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# INHABITED SPACE

## Part One

*B. P. Konstantinov and V. D. Pekelis, Editors*

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16. Abstract

The collection of articles in this book sums up preliminary results of work on prebiology, exobiology, the possibility of life on other planets, cosmic influences on animal and plant life on earth, planetary chemistry, exobiology, and the problem of defining life on other than a carbon basis. The authors are mostly Soviet, with several Western and European authorities included, as well as some American experts.

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## FOREWORD

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The idea of the collection Naselennyy Kosmos /Inhabited Space/ was advanced by the founder of astrobiology, G. A. Tikhov, as early as 1960, but for different reasons its realization stretched over many years. And during this time the developing sciences dealing with space went far beyond the bounds of the problems which had concerned scientists in the 1950's.

With the growing complexity of problems related to the study of space, the range of concerns which this book must encompass also changed and broadened. All this demanded considerable energies from the collective working on the collection. A major contribution were made by the now-deceased Academicians N. M. Sisakyan, B. P. Konstantinov, and V. V. Parin, who have done much to promote the idea of this collection.

The collection Naselennyy Kosmos as it were sums up the preliminary results of scientific advances, doubts, and predictions arising at the very outset of the birth of the space age, therefore data accumulated by science in recent years are not reflected in this book. Some articles in the collection are now of historical interest, while other familiarize us with a fairly recent level of prediction in this field. It is precisely in this comparison that one senses the strenuous steps forward made in space science, and plainly, that the problem of inhabited space --that is inexhaustible and in many respects still not accessible to modern science -- becomes further clarified. It is probable that more than one book will be devoted to this problem -- and in these books the advances of science at the corresponding stages of its development will be mirrored.

It is difficult to point out another field of modern science where problems are so unsettled; therefore scientists at times defending directly opposing points of view have been invited to participate in the collection. In the book this is reflected in the arrangement of the material -- some articles are accompanied by comments and brief information with diametrically opposite statements, and sometimes also with debatable opinion, as yet not conclusively confirmed. This situation must not disturb the readers -- at the growing edge of science a diversity of views, discussions, and debates are not only possible, but even inevitable. It is precisely in these controversies that truth is born.

Today all problems related with any form of life outside the earth fall within the scope of the problem of inhabited space. Therefore articles by specialists dealing with the most diverse problems are included in the book -- from the origin of life to space law and cosmonautics of the future. Naturally the content of the collection as proven to be quite variegated. But it is in this variety that its inner unity lies -- the life-asserting idea of the habitability of space and the sweeping distribution of life in the universe about us.

What is life? How did it emerge from inorganic matter? What heights have been reached in its development? Are there extra-terrestrial civilizations and can any kinds of contact be made with them? /4

We must admit that thus far we do not have exhaustive answers to these questions. However, the strides made in astronautics, astrophysics, radio astronomy, and other sciences directly related to the study of space have instilled in us the certainty that these problems can be solved and solved in the foreseeable future. It is wholly possible that even within the limits of the solar system we will encounter new forms of life unknown to us and this will facilitate solving the most complex problem of modern science -- the problem of the origin of life.

Quite recently astrobiological studies have been limited to the works of G. A. Tikhov and his school -- the comparative study of optical properties of terrestrial plants and martian maria. Today new fields of science such as space microbiology and space genetics are developing. Space biology and space medicine have been progressing vigorously owing to space flights. The problem of contact with extraterritorial civilizations has become the concern of numerous scientific studies and conferences, which demonstrates the urgency of this new direction in human activity.

In the book Naselennyy Kosmos much space is given to problems in space biology, space medicine, and space law. In contrast to the purely astrobiological problems, problems handled by these sciences are particularly practical in nature. Mankind is conquering space at an ever-growing pace. It is difficult to state in which forms the settling of mankind in space and the conquest of the power and material wealth of the universe will occur. But one thing is beyond question: further progress of human civilization is possible only in conditions of peace and the creative cooperation of all nations and peoples.

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# 1. LIFE -- WHAT IS IT?

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"Life is a phenomenon that is extraordinarily tenacious and stubborn. It can exist even in conditions differing greatly from those on earth."

G. A. Tikhov

The question, How did life emerge and develop on earth? has always been in the forefront of interest among naturalists. Data of modern science confirm the materialist conclusion that life is a predictable result of the development of matter.

In investigating the problem of the origin of life, one analyzes a complex of physicochemical conditions that probably existed on earth during the emergence of life and in subsequent periods of its development, and the regularities in the appearance of the chain of processes leading to biological evolution are determined. But to formulate the problem of the existence of life on other celestial bodies, it is vital to determine how universal are the characteristics of terrestrial life for the entire universe. What is the spectrum of conditions essential for the emergence of highly organized forms of matter?

Ascertaining these conditions is a very difficult matter. We know that living organisms exhibit an uncommon adaptability to the most, apparently, unpropitious conditions of existence. The scientific worldview is not contradicted either by the assumption that there is a possibility of more than just the protein form of life. Modern cybernetics affords the possibility of a broad examination of the essentials of life processes without resorting to a specific material substrate. A functional definition of life enables us to examine entire classes of complex self-organizing systems adapted to performing specific tasks in the environments of their habitats.

# AT THE SOURCES OF LIFE

/6

A. I. Oparin, Academician

Among the fundamental philosophical problems in science, the problem of the sources of life, its initial emergence, holds an exceptionally prominent place. How did the initial transition from inorganic nature to the world of living creatures occur? How did the primaeval, most primitive organisms emerge on our earth (and perhaps, not only on it, but also on other celestial bodies); these organisms that in the course of further evolution were the ancestors of the entire living population of the planet? For a long time this question found no rational, scientific resolution and became more correctly a domain of faith rather than of knowledge. Only in the second half of our century (chiefly owing to the labors of Soviet scientists) has a radical change in the relationship of broad circles of scientists in many countries of the world to the problem of life's origin occurred. Still, the fact that rational avenues toward a scientifically valid resolution of this problem were found became especially significant.

At the present time it is becoming increasingly apparent that the emergence of life is not any "fortuitous accident" (as was thought not too long ago). It is a quite predictable phenomenon, an obligatory result of the general growth of the universe. In particular, the evolution of carbon compounds and the formation from them of complex polymolecular systems underlies the emergence of our terrestrial life.

The initial stage of this evolution is the abiogenic formation of the simplest organic compounds (hydrocarbons and their closest derivatives), which is extremely widely distributed in space. It is underway even at the present time on the most diverse objects in the universe. And up to a certain degree, this stage is accessible to our direct study even today, while in the future, as man penetrates into space, our knowledge in this field will become increasingly more complete.

Compounds of carbon and hydrogen, in particular, methane and hydrocarbon radicals, can be detected, on the one hand, on the surfaces of stars (for example, on the surface of the sun), where the temperature is several thousands of degrees and where gravity is very strong, while on the other hand -- in interstellar space, in rarefied gas-dust matter, at extremely low gravities and temperatures close to absolute zero. In this respect, not only is the study of interstellar matter itself of great interest, but also investigations of comets. These cosmic bodies formed under conditions of a nearly interstellar medium are abundant in light hydrocarbons and cyan, which can be readily detected when they penetrate the inner regions of our planetary system. Within the system itself, we detect vast amounts of methane in the atmosphere of the major planets, as well as their satellites. /7

A great deal of attention today is being given to carbon compounds in meteorites, first of all because meteorites until very recently (prior to the analysis of moon soil) were the sole extraterrestrial objects accessible to direct investigation not only chemically but also mineralogically and, secondly, due to the similarity of meteoritic matter with the material from which the earth was formed.

We can detect a considerable amount of carbon in certain meteorites, so-called carbonaceous chondrites. Carbon is present here in its native form, mainly as hydrocarbons and their oxygen, nitrogen, and sulfur derivatives, although extremely complex and high-molecular. Some of them are quite similar to the organic compounds present in terrestrial organisms. Therefore it has even been suggested that life existed on meteorites or on the parent bodies from which they were formed -- asteroids, and that the organic compounds of carbonaceous chondrites are products of the secondary breakdown of extraterrestrial organisms.

Today this view must however be rejected and based on some data obtained it must be recognized that meteoritic organic matter was formed primaevally, abiogenically. Some present-day investigators (in particular, J. Bernal) express the view that organic compounds serving as material for the origin of our terrestrial organisms were formed not only before the emergence of life, but even before the formation of our earth as a planet. In the view of Bernal, they had already been acquired by the earth in ready form in the composition of planetisimalia -- relatively small, cold aggregations of interstellar dust material, similar to meteorites in their chemical composition, from which earth-type planets were formed.

Thus, under this hypothesis our planet must have obtained its initial carbon compounds even during the very process of its formation. Moreover, even after its formation the earth is being continually "nourished" in the past as well as today by organic material arriving on its surface from space together with meteorites and cometary material. However, the quantities these organic compounds is relatively small. Most of the organic compounds that serve at starting material for the origin of life were still evidently formed on the earth surface during the formation of the earth's crust. /8

For example, the eruptions of gas detected recently in the Khibinskiy Massif on the Kola Peninsula are of much interest in this respect. Analysis reveals the presence of methane and heavier hydrocarbons in these eruptions. Careful examination of the physico-chemical and geological environment existing here definitely favors the abiogenic origin of these gases.

Thus, all the data that can be obtained by studying contemporaneous cosmic and geological phenomena convincingly show that during the formation of our planet and in the initial periods of its existence, considerable amounts of hydrocarbons and their derivatives were formed on its surface, serving as the initial material for the subsequent evolution of organic compounds.

How can we find what the pathways of this evolution were? Though direct geochemical observations of the transformation of organic matter in present-day natural conditions outside organisms are of some interest in this respect, their results cannot be directly used to evaluate the course of abiogenic evolution of organic compounds on the surface of the still-lifeless earth (in the so-called pre-actualistical epoch of its development), since with the emergence of life a fundamental change occurred in the conditions existing then in the initial terrestrial atmosphere and hydrosphere. /9

These initial conditions can generally be characterized thusly:

1. The absence of free oxygen in the pre-actualistic atmosphere, which precluded the possibility of the direct, profound oxidation of reduced carbon compounds.

2. An abundance of short-wave ultraviolet radiation penetrating the entire atmosphere and reaching the earth's surface. This provided vastly greater opportunities for abiogenic photochemical processes than those ongoing with longer-wave radiation reaching the earth's surface nowadays.

3. Absence of living organisms with their present-day metabolism, rapidly incorporating into their functioning diverse organic compounds.

Today nowhere on the earth's surface do we have such conditions in a natural setting. The ozone screen in the present atmosphere at an altitude of 30 km blocks the access of short-wave ultraviolet radiation to the earth's surface. The present atmosphere, the upper region of soil, and the entire hydrosphere to the deepest depths are rich in free oxygen and are densely populated with microbes, which on absorbing and eating organic compounds of the environment preclude any possibility of their prolonged evolution, which was indicated even by Charles Darwin in one of his letters.

Thus, even though this may at first glance appeared paradoxical, we must admit that the main reason for the impossibility of the primaeval origin of life today in natural conditions is the

fact that it already emerged and because of this a decided change /10
in conditions occurred on the earth's surface, precluding the possibility of any prolonged evolution of organic compounds by the pathways which were open for them in the primaeval epoch of the earth's existence.

Therefore, we are compelled to construct our hypothesis on the organic evolution preceding the appearance of life by basing ourselves mainly on laboratory experiments, in which physical and chemical conditions that once existed on the earth's surface are artificially produced. Here we start from the widely accepted conviction that the chemical potentialities of methane or other organic compounds are identical in the past as well as today, in the primaeval or the secondary terrestrial atmosphere, as well as in the modern chemist's flask. By consciously reproducing the conditions of the pre-actualistic epoch, we are justified in expecting results on the basis of which we can evaluate the events of the remote past.

Extensive data solidly substantiate the possibility of the formation in a certain period of the existence of our planet of the so-called primaeval broth, that is, an aqueous solution of diverse organic compounds, including such complex and biologically important polymers as polypeptides and polynucleotides, which -- it is true -- exhibit in contrast to modern proteins only a very simplified, randomly disposed arrangement of monomers in their polymeric chains. Of course, much still remains unclear in the study of this stage of evolution and requires further investigation. In particular, we can argue about the general or local concentration of the "primaeval broth" or whether it contained particular compounds, and so on, but in principle the question of the primaeval abiogenic formation of an aqueous solution of organic compounds in the still-lifeless earth can be regarded as settled.

A question of the third, most critical stage of evolution -- formation of prebiological and biological systems -- is much more complex.

Life was not dispersed in space like the compounds of the /11
"primaeval broth." It was represented by organisms -- discrete systems spatially segregated from the surrounding environment, but interacting with this environment in the manner of open systems. The stability of this kind of system and the duration of their existence was determined not by the unchangeability -- the rest, but rather, by the constancy of transformation of compounds, the regular combination of synthesis and decomposition, which in the aggregate constitutes so-called biological metabolism.

Based on all the data which we now have, we cannot assume the possibility of the direct formation of this kind of living system in the primitive solution of organic compounds by their simple self-formation, self-assembly. We do not observe this and cannot artificially reproduce it either with respect to an entire cell, or even its individual organelles.

The gap existing between the "primaeval broth" and the most primitive living creatures could be filled during natural evolution only by prolonged development and the gradual perfection of the organization of some "prebiological systems" -- vastly simpler than organisms -- and capable of spontaneously being formed in the "primaeval broth," by becoming isolated from it in the form of segregated individual formations interacting, however, with their surrounding environment both chemically and energy-wise. This kind of diverse self-filtering system could not only be imagined, but actually obtained in very great quantities. In particular, here we can point to the so-called microspheres of S. Fox or to the coacervate droplets we have prepared. These latter strike us as most suitable, though far from the only possible models for reproducing the phenomena which occurred in the "primaeval broth."

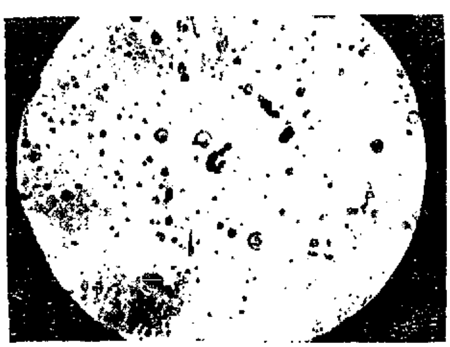


Fig. 1. Coacervate droplets from poly-A and polylysine /12

Their formation requires not only the presence in the solution of polymers exhibiting a strictly specific intramolecular organization, resembling present proteins or nucleic acids. As shown by experiments we conducted in the Institute of Biochemistry imeni A. N. Bakh, USSR Academy of Sciences, coacervate droplets are formed even upon the simple mixing of solutions of the nonspecifically or monotonically constructed polypeptides and polynucleotides. Only molecular dimensions are important. Therefore with the simultaneous synthesis of these polymers, as soon as a certain degree of polymerization in the initial solution was reached, coacervate droplets invariably emerge (Fig. 1).

Thus, the emergence of coacervates in the "primaeval broth" was a direct consequence of the formation of high-molecular primitive polymers in it. Improvement of the intramolecular structure of these primitive polymers during further evolution must have occurred not simply in the solution, but specifically in the indicated polymolecular systems.

Polymers in coacervate droplets exist in a highly concentrated state (50 percent or higher) even when the droplets are /13 segregated from a very dilute solution. Moreover, the droplets are capable of selectively adsorbing various low-molecular compounds from the ambient "broth". If even some of these compounds are capable of catalytically accelerating the reactions ongoing in the droplets, the droplets are converted into open systems interacting specifically with the ambient medium.

In model experiments incorporating diverse simple and complex catalysts (organic compounds and inorganic salts) in coacervate droplets, we induced reactions of oxidation-reduction, synthesis and breakdown of polymers, and so on. In several cases even enzymes were used as the catalyst, though of course there could be no enzymes in the "primaeval broth," but their use gave us tremendous advantages in the laboratory work and therefore we deem it possible to proceed toward this conditionality.

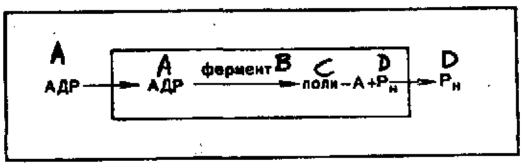



Fig. 2. Scheme of the synthesis of poly-A in coacervate droplets
KEY: A -- ADP [adenosine diphosphate]
B -- enzyme
C -- poly-A
D -- inorganic phosphorus

As an example, we present the scheme from one of experiments (Fig. 2). The droplet represented in the figure by a rectangle, consisting of a polynucleotide and histone and including an enzyme, swam in a solution containing ADP. On moving from the ambient medium to the droplet, ADP polymerizes, forming increasingly newer portions of the polynucleotide (poly-A). The droplet enlarges in volume and weight -- grows -- at its expense, and inorganic phosphorus is given off into the ambient medium. /14

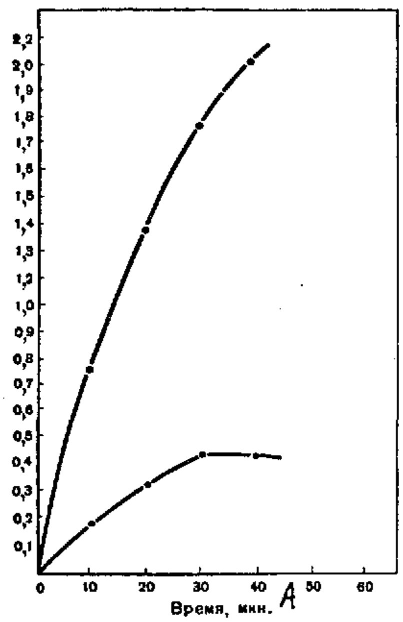



Fig. 3. Scheme of the synthesis of poly-A by polynucleotide phosphorylase in the presence of hexokinase
KEY: A -- Time, minutes

We reproduced in coacervates even more complex schemes of a metabolic flow in which not one, but several diverse reactions were combined and a more rapid or relatively slow droplet growth occurred, while in other cases the droplets were even observed to disintegrate.

Open polymolecular systems sharing a primitive metabolism similar to our models must have emerged readily in the "primaeval broth" as a result of the incorporation into the coacervate droplets forming here of diverse organic and inorganic catalysts from the environment. On increasing in volume and weight, this kind of system (let us provisionally call them protobionts) must have grown in the conditions of the "primaeval broth" and then broken up under the effect of mechanical forces (for example, puncture or wave impacts) similar to the fragmentation of droplets of an emulsion when it is shaken.

The daughter protobionts emerging as a result to some extent preserved the constant character of their interaction with the environment, continually adsorbing from it specific catalysts and /15
thus maintaining the constancy of the ratio of rates and the coordination of the reactions occurring in them.

Of course, this constancy is very imperfect compared with the self-reproducibility of modern organisms. But the so-called "competition" of protobionts in growth and multiplication rates and their distinctive "prebiological selection" may have emerged already on this basis.

To some extent we have succeeded in demonstrating the possibility of this "selection" in model coacervate experiments. For this purpose, a complex of catalysts was incorporated into a single droplet, leading to the relatively rapid synthesis of polymers and the growth of the entire system as a whole in the given environmental conditions. In contrast, in other droplets this catalytic complex was less advanced. Fig. 3 shows how the first variety of droplets grew rapidly, while the second was suppressed in their growth.

Comparative biochemical study of metabolism in the most primitive model organisms enables us to imagine, to some extent, the successive course of the evolutionary development that resulted from "prebiological selection" along the pathways to the emergence of life.

Of course, there still lies a hiatus between our models and the most primitive living creatures, and the main content of the long-term work on the problem of the origin of life that must be stepped up in the immediate future consists precisely in filling this hiatus.

In natural conditions, many hundreds and hundreds of millions of years were required for the foundations of biological metabolism and cellular structure to form in the development of life, possibly much more than half of the time during which life existed on earth. If we clearly imagine to ourselves the full grandeur of this evolution, then any recently occurring, unsuccessful attempts at artificially reproducing the sudden self-origination of life in decomposing broths and infusions of organic compounds would now strike us as laughably naive. Only by finding the pathways along which living creatures were formed during the evolution of matter on our earth will we be able to reproduce them artificially, of course not by the tortuous and slow pathways that nature took, but in relative short time intervals, by consciously selecting in our laboratories requisite conditions and the necessary sequence of phenomena and by replacing natural selection with the guided combination of compounds, systems, and processes. This approach will surely lead us to achieving the cherished dream of mankind -- the artificial synthesis of life.

## SOURCES OF LIFE IN SPACE /7

The first stages of the origin of life may have occurred in space. The American scientist, Doctor R. Berger, reached this conclusion several years ago as a result of his experiments.

Using a particle accelerator, he bombarded with neutrons a mixture of methane, ammonia, and water cooled to $-230^{\circ}$ C. After several minutes urea, acetamide and acetone -- organic compounds essential for the synthesis of more complex compounds -- could be detected in the mixture. The scientist concluded that all these compounds can be formed in space where there are numberless atoms of various elements irradiated with streams of radiation. In his view, even more complex compounds are formed in interstellar space in this way, extending to amino acids, from which as we know proteins -- the basis of life -- is composed.

If this is so, the formation of living matter on planets where suitable conditions exist can begin directly with the organic compounds descending there from space, so-called, from "intermediate products." Of course, living matter did not pass through all /8
stages of development on all inhabited planets. The process may have begun half-way and reached its culmination much faster than on earth.

The experiment leading to these conclusions is interesting even in the fact that in it a relatively complicated synthesis of organic compounds was carried out at a very low temperature at which all compounds are extremely inert and cannot enter into any reactions.

## UNCOMMON FORM OF LIFE

Australian scientists performed a curious experiment, producing an unusual form of life in laboratory conditions. It is probable that the most suitable method of doing this, they judged, is to attempt to compel any of the organisms existing on earth to adapt to conditions which at first glance altogether cancel out life. One of the main elements of living organisms is hydrogen, incorporated, in particular, in the water present in tissues. Bacteria were placed in a vessel containing heavy water induced molecules ordinary hydrogen atoms are replaced with its isotopes

-- deuterium with an atomic weight of 2. In half a year the hydrogen in the organisms of all three bacterial species was entirely replaced with deuterium. Until the bacteria adapted to the new environment, normal cell division in them was upset and deformed formations developed in several bacteria, but then everything returned to normal. It is curious that the new bacteria lost the ability to produce colorant pigments. They became albinos, but then they were able to withstand exposure to heavy radiation doses that are destructive to ordinary bacteria. 19

# A. I. OPARIN'S IDEA FINDS CONFIRMATION

G. P. Vdovykin, Candidate of
Geologo-Mineralogical Sciences

At the present time living systems in earth conditions, after dying and being buried in sediments, undergo degradation. The end-result of the transformation of these biogenic compounds in reducing conditions are the very same organic compounds found in meteorites and in the products of abiogenic synthesis. The organic matter in rocks, as we well know, has passed through the stage of animate matter.

The general similarity of organic compounds formed by abiogenic synthesis from the simple starting compounds, and the terrestrial organic compounds of biogenic origin points to the similar transformation of carbon compounds independently of the location of their transformation (whether in terrestrial conditions or in conditions that were ancestral for the meteoritic bodies), and also the origin of organic compounds (abiogenic or biogenic).

This once again shows that biogenic evolution in earth conditions must be viewed as part of the overall transformation of carbon compounds in nature. /10

At the present time there are no data to suggest that at least within our solar system there are any other forms of life besides the form founded on carbon.

All this completely confirms the concept of A. I. Oparin on the spontaneous origin of life.

## HOW DID THE LEAP OCCUR?

I. S. Shklovskiy, Corresponding Member
of the USSR Academy of Sciences

At the present time it is difficult to agree with the hypothesis of A. I. Oparin. The presence of analogs of metabolism and "natural selection" in coacervates still does not yet prove that there are primitive living organisms. The main qualities of any living organism is the presence of a "copying system," a "code" transmitting to its progeny all the characteristic features of a given individual. There is nothing like this in the coacervates. /11

The hypothesis of A. I. Oparin leaves completely unexplained how the leap from the inanimate to the animate occur. Only resorting to the main concepts of modern molecular biology as well as cybernetics can assist in solving this most important, fundamental problem, some approaches to which have already been outlined. A vital question is the possibility of the synthesis of DNA in natural conditions of the "primaeval" earth. Successful attempts at the synthesis of DNA and RNA (ribonucleic acid) in laboratory conditions were made by Kornberg. However, the conditions in which biosynthesis of DNA occurred in the laboratory can scarcely have existed in the primaeval ocean. Moreover, Sagan presents a number of interesting arguments in favor of this assertion. The decisive word in this most important problem awaits future biochemical and genetic research.

## INHABITANTS OF THE STRATOSPHERE

The stratosphere at an altitude of 15-20 km, where the air temperature is -55° C, has been found to be inhabited.

This was discovered fairly recently. American scientists placed in the gondola of a balloon a pump that pumped air through a special filter. After the pump had drawn in 5500 cubic meters of air at an altitude of 15-20 km, about 20,000 orange-yellow bacteria were found on the filter. No bacteria were encountered at lower altitudes. And even at the ground surface the concentration of the orange-yellow bacetria is one-third of that in the atmosphere. /12

The chance flight of bacteria into the stratosphere is precluded, since in contrast to terrestrial microbes consisting of the most diverse species, the bacteria in the stratosphere were found to be of strictly one species. The orange-red coloring evidently indicates that that the bacteria can efficiently use ultraviolet rays, which are especially intense in the stratosphere. But from where these "sky" bacteria obtain, for example, phosphorus for the organism remains a puzzle.

A second flight of the balloon did not capture a single bacterium. It is unknown whether this means that the first experiment was in error or whether the bacteria float in clusters in a kind of unique "cloud".

## IDEA OF NONPROTEIN FORMS OF LIFE IS WHOLLY WITHOUT FOUNDATION /13

Three questions to Academician V. A. Engel'gardt:

1. In your opinion, are nonprotein forms of life possible?

2. Nowadays we often have occasion to hear about "life" and "nonlife" at the molecular level: "living molecules," "living protein," and so on. Are these descriptions reasonable and in this respect, what are the main features of life, in your opinion? Do the new advances in science add anything new to these definitions?

3. What are the prospects for the artificial synthesis of "life" and "nonlife"?

1. On the question of "nonprotein" forms of life. Metabolism is an obligatory attribute of life. All metabolic reactions occur under the effect of enzymes. All enzymes are proteins. Hence it is clear that the hypothesis of "nonprotein" forms of life is devoid of any foundation.

2. Such expressions as "living molecules," "living protein," and so on are personally regarded as fundamentally incorrect. Life is above all characterized by an entire set of characteristics: the capacity to reproduce after one's kind, metabolism, transformation of energy, excitability, and irritability, and so on. There are no grounds to assume that these sets of properties can belong to any single isolated type of molecule. /14

The most important achievement of science of the living world, in particular, molecular biology, is the fact that many of the individual manifestations of vital activity enumerated can be reproduced in ideally simplified conditions and systems approximating the molecular level and sometimes amounting to the participation of some particular type of molecule.

At the same time it must be stressed that drawing a boundary between life and nonlife becomes increasingly more difficult and the definiteness of this demarcation is diminishing. As an example, we can point to viruses, which in the words of Staply, outside the living cell are "dead as stone," but within a cell reveal many features of a living formation.

3. From the foregoing it follows that we can scarcely now speak of the synthesis of "life". Evidence of the amazing advances

in science is the fact that such paramount components of living formations as proteins and nucleic acids have been prepared by pathways of chemical synthesis (or in artificial noncellular systems).

## WHAT PRECEDED LIFE /16

J. Bernal, professor (Great Britain)

In discussing the problem of the origin of life, we cannot gather immediate data, and comparative investigations are impossible at the present time. We hope, however, that this possibility will come to light in the immediate future when manned space flights will be able to detect other forms of life.

Are the forms of life existing on earth accidental or necessary? In other words: if life were to be found on other celestial bodies, then would it differ from the forms that we find on earth? At the present time we have no grounds to expect the identity of forms of life on earth and on other celestial bodies. At the same time we know quite a great deal about the chemistry of the elements in the periodic system and we know that other elements do not exist; therefore there are no grounds to expect the discovery of any forms of life constructed from altogether different elements. This follows, first of all, by the fact that life on earth is based on the most widespread elements encountered on the sun as well as in stars; and secondly, this follows from quantum calculations of the energy exchange of atoms such as silicon and arsenic, calculations indicating the possibility of the facile realization on their basis of enzymatic reactions typical of terrestrial forms of life.

We have not touched on the question as to whether life arose spontaneously. We do not wish to prove the actual fact of the origin of life, but to show how it occurred. Among the possible ways in which life emerged, we wish to single out one, the actual way. The Oparin-Haldane hypothesis has removed this problem from the realm of pure speculation. Experimental work has begun on syntheses, however even though such studies are of vital importance to chemistry, we must show that the systems occur in conditions similar to those in which, as there is reason to assume, life emerged. In this respect I wish to point out that our experimental work, of independent importance, can at the same time have no relationship to the question of the origin of life.

The synthetic approach to the problem of the origin of life requires a certain probability of the presence of the compounds from which life emerged and of the conditions in which this occurred. Since we are not now limited to the question of the origin of life on earth but are considering the problem of the origin of life in general form as a problem of the origin of prebiological forms of complex compounds of carbon and nitrogen, we must also take account of special problems in the astrophysics of stars and nebulae.

Any well-founded theory of the origin of life must explain the existence not only of compounds encountered in modern organisms, but also of carbon compounds detected in meteorites /17
and in igneous rocks.

We wish to resolve yet another problem: are these two lines of proof consistent? In other words, are the carbon compounds found in meteorites actually similar to compounds found on earth originating, as we can assume, through the vital activity of organisms?

The carbon fraction of meteorites consists of compounds with high molecular weights that are very difficult to analyze; methods developed for organic compounds of biological origin forming on earth are inapplicable to them. It is possible that this material is an amorphous mass consisting of carbon, nitrogen, hydrogen, and oxygen, such as, for example, charcoal. It can assist in the primary and secondary forms. The primary form found in meteorites is possibly associated with silicate hydrated at relatively low temperatures. However, these structures have been found in meteorites accompanied by relatively high-temperature forms.

There are alternative series for the origin of carbon chondrites. Mueller develops the concept of their volcanic origin. I support this theory, suggesting a mechanism of asteroid formation according to which carbonaceous chondrites derive from an intermediate layer where they can be formed at moderate temperatures and ultimately were ejected by volcanic processes. Another theory, decisively supported by Wood, states that carbonaceous chondrites are specimens of primary matter and were condensed from a dust cloud surrounding the earlier-formed sun: primary dust particles were fused by the shock wave, and then rapidly cooled. This is confirmed by the glassy nature of small chondrites. Their age is approximately 4.2 billion years; the presence of relatively large amounts of xenon-128 formed from iodine-128 -- a radioactive /18
development with a short half-life -- indicates that the formation of chondrites from the dust cloud surrounding the sun lasted for several millions of years.

Chondrules are embedded in the principal material containing the carbonaceous material and silicates, which according to Kerrige's data, are analogous to serpentines. Some of them contain water of crystallization enriched with deuterium.

According to recent data of Wood's, the content of xenon in the overall chondrite is smaller than in the chondrules; therefore, the intermediate material is relatively younger. Many chrondrites, in particular those not containing carbon or containing it in small amounts, reveal traces of subsequent metamorphoses into achondrites with ophitic structure. Clearly, however, the carbonaceous material containing hydrated silicates was not subjected, after its formation, as yet to temperatures above 150°, since the organic material as well as dehydrated silicates decompose at the temperatures.

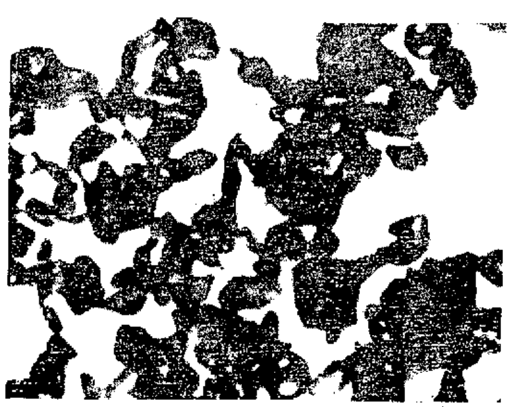
The theory of chondrite formation from molten dust can prove compatible with the volcanic theory, if it is assumed that chrondrites containing large quantities of carbonaceous material comprised the surface of the asteroid, which was never heated and contained a mixture of compounds trapped when the asteroid was formed and falling onto it later as volcanic dust. This problem can probably be resolved relatively soon, when we acquire samples of soil from the surface of the moon and samples of meteoritic dust, especially from noctilucent clouds.

The question of carbonaceous material in meteorites is related to various hypotheses of the origin of life. Based on a study of hydrocarbon fractions, Nagy and Menshein state that the carbon in meteorites is of biogenic origin and that, therefore, life existed on asteroids that were the parental bodies of these meteorites. This is a highly debatable question, first of all because it is difficult to interpret analyses and secondly, because it is extremely difficult to account for the origin of life on celestial bodies that probably had no hydrosphere. However, there is no reason here to discuss these problems in detail; of importance to us is the fact that meteorites contain complex natural organic compounds, all the way up to purines and pyrimidines. And even the very effect of their presence in meteorites requires a considerable modification of the initial Oparin-Haldane hypothesis as regards the section dealing with the primaeval formation of carbon compounds.

Meteorite Staroye Boroskino, black (carbonaceous chondrite) and the white Staroye Pes'yanoye meteorite /19

The new hypothesis of the origin of carbon compounds which I advance consists in the statement that initially low-temperature gases condensed on the surfaces of metallic iron and silicate dust. These compounds probably consisted of ice,

and also -- at lower temperatures -- of ammonia, methane, or $CH_2$ radicals. With a slight temperature rise (due to the penetration of sunlight through the primary dust clouds) they would be volatilized, though not completely, evidenced by the fact of ice being detected in noctilucent clouds. Moreover, in some cases a small part of the material may have polymerized due to the action of radiation, whose source consisted of solar flares or cosmic rays. This polymeric material, exhibiting high molecular weight, would no longer vaporize together with the ice and the condensed gases. These assumptions find confirmation in the data of Duchesne, who detected free radicals in carbonaceous meteorites. Moreover, the proposed hypothesis is in agreement with what we know about the structure of these meteorites. They consist principally of very old olivines formed at high temperatures, or else of enstatinic chondrules situated in the softer matrix, of carbonaceous material and hydrated silicates. The amount of deuterium detected in it exceeds by a factor of four
its content on earth at the present time; this shows that these /21
meteorites are the remains of a hydrated shell and indicate a prolonged period of selective evaporation of water and concentration of deuterium.



Particles of meteoritic dust found in the vicinity of the fall of the Sikhote-Alin meteorite /20

At the present time factual data are rapidly accumulating in favor of the concepts just advanced above. These data were gathered from studying meteoritic dust found in red-colored clays on the ocean bottom and in the icebergs of the Arctic and Antarctic or accumulated on oceanic islands, as has been done by Parkin. It appears that in all cases the initial particles consist of an iron-nickel core, which can oxidize generally to magnetite when exposed to atmospheric gases or sea water; at the same time particles of lesser size can descend slowly down to sea level without being oxidized. Evidently, they have an organic core capable of oxidation. In subsequent studies, it was possible to examine this dust in situ in noctilucent clouds; this was carried out by a joint Swedish-American expedition in the summer of 1962.

The clouds themselves probably consist mainly of fine ice particles. Each particle has a core -- a most minute spherical body that consists of a particle of 0.05-0.5 micron diameter cosmic dust. However, thus far no carbon could be detected in these particles.

These kinds of investigations will doubtless shed light on the possibility of the cosmic origin of the hypothetical material, which was earlier called primaeval broth, and the first sources of free energy needed for further chemical transformations leading to the origin of life.

There a much higher probability that these compounds formed on a substratum whose surface considerably exceeds its mass. This can altogether replace the concepts of the formation of sufficient amounts of primary carbon compounds on the surfaces of planets /22 such as the earth, regardless of any dependence on transformations by the oxygen-rich primitive reducing atmosphere. According to the meteoritic theory, small planets, including the earth formed as a result of the accumulation of dust formed as the result of the accumulation of chondritic bodies. It appears probable that carbon compounds found later on the earth's surface -- it is precisely from these that life began, according to the theories -- comprised only a small portion of the material falling on the earth and initially comprising its mass.

The reason why I am prone to attribute so great an importance to meteorites in constructing a theory of the origin of life (although they have been completely left out of the picture by earlier theories) is that meteorites contain the only primitive carbon compounds known to us. What we know about the replenishment of the earth's surface as the result of the movement of continents, formation of mountains, and ocean depths indicates the impossibility of the direct comparison of the compounds formed with those that, as we assume, were formed in relatively isolated conditions in other parts of the solar system, the ages of which are known.

It appears at first glance that shifting the first stages of the origin of life from earth to space will lead to very decided differences in the chemical theories of its evolution. However, in fact this difference is less than we could anticipate. On the one hand, the composition of the "primaeval broth" formed as the result of photosynthetic processes in the primaeval atmosphere is hypothetical to the highest degree. On the other hand, experiments of Miller and others showed that the same compounds can be formed through a large number of processes from extremely dissimilar starting elements. The principal feature of these compounds is the fact that all of them in the biochemical sense are abiogenic, they were all formed without the participation of enzymes. In the extreme case very simple nonspecific catalysts such as complexes of iron and nickel were necessary.

The emergence of organisms, that is, the conclusion of the second stage in the genesis of life, could scarcely be understood without a great deal of experimental work, including studies in physical and colloidal chemistry. Only by this approach are we able to clarify how the initial stages of life actually took place long before the emergence of organisms, in particular, whether they required, as I suggested at one time, the presence of molecular layers adsorbed on clay particles or disseminated into clay or crystals of iron hydroxide. /23

In studying the microstructures of living organisms, we can arrive at indications of their origin. On the one hand, here we will probably be able to find certain general principles governing not only life on earth, but also life under other conditions. On the other hand, characteristics typical of precisely terrestrial life may come to light.

The general philosophical question arising from an analysis of the data of modern molecular biology is that nearly all structures or functions are the result of what has been called prescription. The DNA chain does not contain anything that could be called a description of structure, that must be formed, or activity that must be manifested; templates of specific behavior evidently are genetically built into the animal organism. They emerge as the result of receiving specific instructions, and the end result is incorporated in these instructions, which must be realized via a long series of indirect displacements. By our anthropomorphic or, more precisely, technomorphic view of things, a produced object or a function characteristic of it are regarded as produced in advance. Man works by plan: even if a person carrying out a given instruction does not fully imagine to himself the entire plan, he still knows that someone arranged this plan. Obviously, in nature everything proceeds otherwise. In the strict sense of the word, nature does not "create", though in the more profound sense perhaps this is what it does. Actually, on examining in its full complexity the problem of the /24
self-evolution of chemical or structural mechanisms on which life is based, we arrive at the conclusion that these mechanisms cannot have pre-existed in advance in the form of some concept.

We must study how the instruction became modified as the ultimate organism took form. The question of the possibility of inheriting acquired characteristics obviously must be reexamined anew in the light of recent data from molecular biology, and it is quite possible that it will prove to be inconceivable.

The concept of instruction can prove fruitful when applied to the problem of evolution, especially to the problem of biochemical evolution at early stages of prelife and life. When molecules interact in a medium in which communication between individual parts of a system is difficult, the chain of processes beginning with some random event can set up conditions capable of influencing all reacting molecules. Applying this molecular analogy to the Darwinian concept of the survival of the most adapted organisms, we can state the processes which lead to economy of material or of free energy will predominate (Horowitz's principle). This enables us to some extent to understand and evaluate the limits in which existence and development of life is possible.

It is hazardous to attempt to draw generalizations based on a single example. This assertion is valid also for life on earth, though it has been studied very closely. It is how obvious that all self-reproducing systems have some general chemical properties. They must continually maintain the activity or, in any case, in some manner oppose its rapid changes. In other words, they must satisfy the laws valid for the thermodynamics of an open system, whose entropy remains approximately constant due to the free energy influx. A necessary condition is, further, the /25
preservation and reproduction of structure through molecular reproduction also necessary in setting up any structure capable of being formed spontaneously via modifications or crystallization. This in turn subsumes copying of information (variations are admitted only infrequently), storage of information, and the mechanism of information transfer. Geometrical considerations compel us to assume that the transfer of information occurs via a polymeric chain, that is, is principally linear in character. In terrestrial forms of life the transfer of information is carried out by means of nucleic acids. It is possible that in other forms of life this role will be carried out by other polymers, for example roles in which the bonds between two bases containing phosphorus is realized not by means of a phosphate.

These considerations compel us to doubt that only a single pathway of the origin of life exists. We can define life as a form of dynamic realization of quantum characteristics of atoms. All forms of life on earth are unified in the chemical sense, but infinitely diverse in their morphology and manifestations. Life is continuously genetic and evidently it existed through most of the earth's history. Life is self-sustaining and self-modifying. It is possible (though this cannot be proven) that life in the form in which it exists on earth emerged after the extinction or displacement of earlier prelife forms. If this is so, then this occurred at a very early stage. However, this in turn does not at all denote the invariability of life in the universe:

it is probable that other quite different forms exist. I wish to stress that when speaking about other forms, I do not have in mind differences between organisms in the same phylogenetic group or differences between phylogenetic groups of organisms on earth; I am talking about differences and characteristics that are common to all types of organisms in general, -- I have in mind the presence of nucleic acids, proteins, enzymes, and so on.

The nature of earth life is determined by the properties of /26
the hydrosphere. The biosphere, which is part of the hydrosphere, acquires in a certain period of time the characteristics that it retains to the present. Radically new forms of life can now emerge on the earth only in the laboratory.

The emergence of forms of life fundamentally distinct from each other is possible only in separate non-communicating biospheres. These forms of life can develop on a limited number of planets in our own or in other solar systems. From physicochemical considerations it follows that any possible form of life requires the presence of a liquid aqueous medium; this means that the biosphere of any planet will develop as part of the hydrosphere. Therefore, a suitable location for the development of life can be only planets with a hydrosphere. Hence the mean temperature of radiation must lie with the limits 0 and $100^{\circ}$, more accurately, probably between 20 and $60^{\circ}$, and gravity must be strong enough for water not to be dissipated from the planet's surface into the surrounding space. In other words, at a given temperature, the mean velocity of water molecules must be lower than their rate of evaporation. Therefore, within the limits of our solar system life is possible only on earth and on Mars. It is too hot on Venus, and the moon is too small.

When this analogy is extended, terrestrial life can be regarded as one community: all living systems composing it have a common origin and are distributed only on earth. On other planets, if there is life on them at all, completely different communities will develop, which in principle cannot be confused with the terrestrial community.

Nonetheless, certain general features are entirely possible, which I will refer to as common properties of life. All this is encompassed in a system of hypothetical general or invariant biology, whose limits remain yet for us to determine. There likely will be as many biologies as there are individual communities of life. It may be that this delineation will not always be as absolute, and perhaps may not exist at all where communication has been achieved between planetary systems. In this case competition between communities is possible, as well as evidently some displacement and adaptation of the communities. We can imagine to ourselves some "superlife" resulting from combining the best found in different communities.

# LIFE CAN HAVE AN ARTIFICIAL ORIGIN /17

I. S. Shklovskiy, Corresponding Member
of the USSR Academy of Sciences

Owing to the possibility of synthesizing living matter (not necessarily rational matter) from inanimate matter, a large number of acute problems arise. Let us dwell, for example, on the following problem. Since there is no fundamental difference between natural life and artificial life, we cannot cancel out the possibility that life on some planets can be of artificial origin.

Thus, it is not without interest, for example, to discuss by way of a hypothesis the possibility of transporting living spores and microorganisms during a visit to a lifeless planet by an inadequately sterilized spacecraft from another planet. We can also raise the hypothesis of a much more radical property: life on some planets may have emerged as the result of a conscious experiment by highly organized cosmonauts visiting these planets at some time which have then been lifeless. We can even suggest that this kind of "resettling of life," so to speak, "in a planned manner" is the normal practice of highly developed civilizations scattered throughout the expanses of the universe. /18
Instead of passively waiting for the "natural" spontaneous origin of life on a suitable planet -- a process that is possibly of very low probability, highly developed galactic civilizations supposedly could sow life in a planned way throughout the universe ....

If so, the probability that planetary systems in our galaxy are inhabited can be increased by many orders of magnitude. Finally, in order to be consistent, we must once again allow for the possibility of the populating of planets on which suitable conditions exist by rational creatures -- artificial or natural.

Of course, these hypotheses are most general in nature. We by no means assert that any concrete scientific arguments exist in favor of the conclusion that life on earth, still less rational life, is of artificial origin. Our aim is to focus attention on the possibility of this phenomenon on the scale of the universe and on the consequences that derive from it.

# EXCHANGE OF LIFE BETWEEN GALAXIES /19

B. A. Vorontsov-Vel'yamilov, professor

In recent years reference has been made more often than earlier to the possibility of transplanting mankind to a planet on another star. It is intended that this can occur when the energy transfer of our sun becomes too low. Discussions concerning flights to other stars (and back again!) rest on the current advances in astronautics and the paradoxes of the theory of relativity. I do not share the view of the optimists: planets in other solar systems suitable for "good" life are too remote. Even the idea of transplanting mankind does not solve anything fundamentally, since the reserves of energy in any star even in our own or in neighboring galaxies are still limited.

However, I wish to point to transplanting of living creatures from one galaxy to another that probably already has long since occurred and which took place without any efforts on their part.

In studying stellar motions, it was found that in our galaxy some stars travel at hyperbolic velocities, reaching several hundreds of kilometers a second. This perplexed astronomers, since such stars cannot revolve around the center of our galaxy. The attraction of the galaxy cannot hold them, and they /20
always be in flight from our stellar system. Incidentally, it is also not clear how they acquire this velocity.

More than ten years ago I suggested the following possible explanation. At the periphery of galaxies, especially dwarf galaxies, even moderate perturbations are capable of so increasing the velocity of the star that it will always separate from its system and, by wandering, can fly off to another galaxy. It will preserve in addition to its velocity relative to its own galaxy the velocity of this galaxy as a whole (and in fact the relative velocities of galaxies are in the hundreds of kilometers a second!). So the star is capable of flight to another galaxy at a velocity that it is hyperbolic with respect to the latter. The attraction of the galaxy to which it flew will promote an increase in the star's velocity.

When interacting galaxies with intense perturbation of forms (and of movements therein!) were discovered in 1957, possessing a common shell, I wrote that partial exchange of matter, that is, of stars, is possible in them. Later the American husband-and-wife astronomer team Burbidge reached the same thought, in studying the distribution of luminosities in two interacting elliptical /21 galaxies penetrating each other. Especially large numbers of stars can fall from one galaxy into another in the intimate pairs of interacting galaxies. Among the stars there can even be those that have planets. In turn, given forms of life can exist on these planets.

Interacting galaxies sometimes penetrate each other. Stars from one galaxy can be distant from the stars of the other galaxy by, let us say, 1000 parsecs. At a relative velocity of 100 km/sec, a voyage over this distance will take about $10^7$ years, that is, one-hundredth of the age of life on earth. Even in less favorable conditions, the "forced" transplanting of the inhabited planet to another galaxy is altogether possible. However, if we do not bear in mind the intensity of cosmic rays, this "transplanting" could change nothing in the conditions on the given planet, since it will as before face its same star -- its sun. Nonetheless, the possibility of these cases is extremely fascinating and thus far has not entered the minds even of science fiction writers.

# ON THE WAY TO DISCOVERING THE NATURE OF LIFE /22

V. A. Engel'gardt, Academician

The field of study of the living world is extremely diverse, but it is clear that one question -- the nature of life -- stands at the center of attention. Just what is life, what are the most promising avenues to discovering its nature and principles? An answer to this question is given by the very development of present-day biological science in which research into the most complex phenomenon in simple conditions is gaining growing significance. Studying phenomena typical of living organisms and investigating objects that are devoid of life or lie on the border line between life and nonlife -- this trend underlies the youngest and the most vigorously developing direction in biological science, which has been called molecular biology.

The birth of this field of biology is related to the fact that it proved possible in very simple systems (down to the molecular level) to reproduce the most important manifestations of vital activities -- respiration, locomotion, light perception, and reproduction. All this was done, it is true, separately, in different conditions of chemical and physical experimentation during which chemists analyzed a compound, physicists studied and /23
established its physical structure and properties, while biologists in union with them observed how this compound performed given biological functions. This is the realistic approach toward the production by artificial means of living formations and the simplest forms of life. But here, of course, above all we must firmly stipulate what we mean by the definition "life".

If we take any one of the characteristics of life -- for example, the ability to reproduce, then we can say that in recent years molecular biology has already closely approached this frontier. It has been found possible to place several kinds of molecules in a test tube, add some chemicals and some biological enzyme-catalysts, and then observe how these molecules begin to reproduce. If we put in a thousand molecules, then after some time many billions of such molecules or even more will be found in our test tube. Thus, it has been possible to reproduce the multiplication of molecules, but we cannot say that these molecules are living.

In a similar fashion, we can compel the molecule of our blood -- hemoglobin -- to combine with and release oxygen, and we will see how the molecule carries out this process, how it changes in /24 so doing. We say that the molecule breathes. But can we say that this molecule is alive? Scarcely. Life is a highly complex set of a large number of characteristics and properties, whose reproduction in a single object we have thus far been able to achieve. But the fact that we are approaching this to an ever-growing degree is beyond question.

Advances in molecular biology in recent years have so surpassed all that could be anticipated 20 years ago that we are now in a position to expect that the most difficult goals are attainable.

In the study of living objects, nowadays investigators focus their closest attention on two kinds of compounds -- proteins and nucleic acids. The entire mass of our body is constructed of proteins, while nucleic acids, as we know, are closely associated with the phenomena of heredity and the synthesis of protein in an organism. Though research in this field began quite recently, already major successes have been won. Twenty years ago one could scarcely assume that chemists would be able to synthesize the protein molecule, but today this has been done; 20 years ago we knew very little about nucleic acids, but already today we /25
have clarified subtle features of the structure of several types of these molecules. A major role in the progress made in this field of biological science belongs to Soviet scientists. For example, they not only have established the structure of the nucleic acid molecules -- it has been found possible to divide it into two parts, in half, and to prove that the molecule thus, of course, loses its properties.

And later on it became possible to again bring these two parts into contact and under certain conditions to establish that in the "sewn" molecule some of its former normal properties are restored.

What is the result of this kind of surgery at the molecular level? Here possibilities of entire new approaches to solving delicate and complex problems involving the mechanism of protein synthesis and the transfer of hereditary information are opening up, however a decisive answer to this question still awaits its future research.

For the moment we can only state that these studies have drawn tremendous interest from scientists and outstripping what has been done in other countries.

## LIFE AND THINKING AS SPECIAL FORMS OF THE EXISTENCE OF MATTER



A. N. Kolmogorov, Academician

If we carefully analyze the construction of the article "Life" by A. I. Oparin in the Bol'shaya Sovetskaya Entsiklopediya /Great Soviet Encyclopedia/, we can easily find that the main properties of life as a special mode of the organization of matter described in the article lend themselves to a formulation abstracted from the specific nature of elementary physical (in particular, chemical) processes that underlie it:

a) "Any organism lives and exists while more and more new particles of matter and their inherent energy are conveyed through it in a continuous flow." The matter arriving at the organism undergoes profound changes, acquiring structure similar to the structure of the matter already incorporated into the living body. "Specific to living matter" is the fact that these transformations of matter "are organized in a definite fashion in time, are coordinated with each other into an integrated system ... and in their totality are directed toward the constant self-restoration and self-preservation of the entire living organism..."

b) "Profound study ... led to the conclusion that this order is nothing that is external, independent of the living body (as idealists claim); rather, at the present time we ... know that the rate, direction, and interaction of individual "processes occurring in the organism, that is, "all that the order under study comprises" is entire determined by the "relationships that are set up in the living body, in its unity with environmental conditions."

c) "Most obvious" of the other simplest qualities of living bodies is the "ability for self-reproduction inherent in living bodies." Self-reproduction of living organisms does not reduce to the multiplication of the simplest structures constituting these organisms. These simpler structures can be formed in the organism in a regular fashion de novo. "The sequence" of processes "underlying this regeneration" "depends not on some single isolated factor, but reflects the entire organization" of a given living body in its "direction with the environment."

d) "... Irritability as a special form of communication of the organism with environmental conditions is intrinsic to all life, including the most primitive living creatures."

e) "In addition to growth, irritability, and other manifestations of life, the ability to reproduce ... is one of the fundamental properties of living bodies."

f) "... Progress in the material organization of life consists ... in the ever-growing differentiation of a living body into parts and the segregation of these parts into groups or organs with different ... functions."

g) "The historical experience of all preceding generations is embodied in heredity." Heredity and variability are among the "characteristics of life" that "acquired decisive significance for all the subsequent development of the organic world ..." /28

These series of assertions by A. I. Oparin can serve as a solid foundation for a definition of life abstracted from the specific nature of elementary physical processes, whose specific organization gives us a basis to call their integrated systemic ongoing occurrence phenomena of life.

In the "historical experience of all preceding generations", "irritability", and so on, a cyberneticist easily recognizes specific biological forms of the manifestation of the general concepts of the accumulation and storage of information, feedback, and so on familiar to him.

We have singled out this abstract series of logical constructions of A. I. Oparin's perhaps against the author's wishes. To do this, by breaking up the exact phrases of the excerpts, we had to replace some specific terms with more general ones; for example, chemical transformations -- replaced by change in the structure of matter in general, and so on. For the rest, our presentation follows A. I. Oparin's line of reasoning quite closely.

Actually, thus far we are familiar only with the world of living creatures inhabiting the earth, with a common history of origin and development. For all of its grandeur of scale, this is a single phenomenon having occurred and continuing to occur in a specific place and a specific time interval. Until recently, the question of whether the word "life" is an individual name of this world of living terrestrial creatures united by a common history or whether it expresses a general concept relating to an unlimited number of systems of living creatures emerging and developing independently in wholly different conditions, was essentially quite idle. It appears to us that A. I. Oparin has shown great wisdom in constructing his article so that the general declaration "Life is a special form of the motion of /29
matter emerging at a specific stage in the historical development of matter and represented on our planet by a vast number of separate individual systems -- organisms" -- did not receive

further development in the subsequent exposition. As far as life actually existing on earth is concerned, then the statement of A. I. Oparin that "all subsequent development of biology brilliantly confirmed" the statement of Engels' "characterizing protein bodies as the material carrier of life ..." is unquestionably correct as applied to terrestrial life.

The emphasis given to the unity of common physicochemical principles of the structure of all living terrestrial creatures, as well as the unity of history of the organic world actually developing on earth played a very great progressive role in the development of biology. It is sufficient to recall that primitive ideas of the possibility of "spontaneous generation" of living creatures in lifeless matter, bypassing all the highly involved history of organic evolution, had to be refuted not so very long ago. Therefore, definitions of life that involve essentially, in compressed description, the main features of the single form of life known to us have been progressive until recently.

The situation was exactly the same with the concept of thinking, until recently. Actually, we are familiar only with thinking and "elementary, concrete thinking" (I. P. Pavlov) of higher animals, which is cerebral activity.

However, today the situation is changed owing to two very real factors. The first of these is that in the age of astronautics a genuine possibility has risen of encountering new forms of the motion of matter exhibiting fundamental properties of living or reasoning creatures of practical interest to us. The second factor is the manifestation in principle of the completely unlimited capabilities of simulating any complexly organized material systems offered us by modern computer technology.

Both these factors urgently demand that the definition of life and thinking be liberated of arbitrary assumptions on the specific nature of the physical processes underlying them in order for this definition to be purely functional. This treatment of such general ideas of life and thinking is still a matter for the future. But the broad outlines of these future definitions are quite clear. /30

From the wider philosophical point of view, we are speaking about an exact objective description of conditions in the material environments developing according to specific laws of cause and effect without any goal set up from without for this development, where material systems emerge that cannot be understood in functioning and development apart from enlisting an altogether new series of concepts, without ideas of the internal purposefulness intrinsic to the systems. In general outlines the solution of this problem is afforded by dialectical materialism. But the

classics of dialectical materialism revolved about, as a specific group of phenomena amenable to explanation, which was natural until recently, the world of living terrestrial creatures associated by the commonality of their origin, at the mental life of higher animals and human thought. Now the time has come when it is necessary to represent more concretely the avenues along which material systems exhibiting internal purposefulness emerged, in their full commonality, without neglecting either the capabilities that have not yet been directly observed. At the present stage, here we must not neglect either the construction "in reserve" of several arbitrary hypotheses, however close this activity of the scientist sometimes approaches the constructs of science fiction writers. Each of the hypotheses advanced, for example, in a book by I. S. Shklovskiy, Vselennaya, Zhizn, Razum /Universe, Life, Thought/, exhibit only a moderate degree of plausibility. But as a set of possibilities suitable for discussion and not contradicting the store of data presently available to us, the constructs of I. S. Shklovskiy strike me as very valuable. The selection of /31
these capabilities suitable for discussion has been done with great taste and great knowledge.

Special mechanisms for the storage and processing of information were elaborated already at the earliest stages of the development of life. Initially improvements in these mechanisms occurred by means of "blind search." This is still the mechanism for the elaboration of the simplest conditioned reflex. But now mechanisms ensuring the proper reflection of the situation of the external world regardless of whether this reflection in all details at a given moment is necessary for the elaboration of behavior acquired some independence at a fairly early stage in organic evolution. Mechanisms of internal simulation of the possible course of phenomena in the external world and the possible consequences of a given line of behavior emerged later. These mechanisms made it possible to synthesize complicated purposeful complexes of behavioral acts, bypassing numerous trials. Naive concepts to the effect that before a difficult leap a cat "reasons out" the techniques of execution correctly convey the uniqueness of this synthetic activity of the brains of higher animals. Human reasoning has not been far removed from this even to the present time. Today it has become urgently necessary to describe in more concrete detail what we understand by the word "thinking" in terms applicable to an arbitrary system about which the proverbial question "does it think" or not arises.

When the functional point of view is consistently applied to life and thinking as modes of the organization of a material system, we naturally arrive at conclusions that can cause us some perplexity. The point is that simulating the mode of organization of a material system does not consist in anything other than in setting up using other material elements a new system exhibiting in its essential features the same organization as the system being simulated. Therefore a complete enough model of a living creature can be properly called a living creature, and a model of a thinking creature -- a thinking creature. /32

Some science fiction writers maintain that all of advanced life resembles each other. In their view, representatives of all (or all "good" and not "bad") extraterrestrial, highly developed civilizations must have two eyes and nose, though perhaps of somewhat unusual form. Their bodies must be so similar to the human form that on seeing them without clothing we will be amazed at how close they correspond to our ideals of physical beauty, and so on.

Unfortunately, it is difficult to find rational grounds for these ideas. An even if we were fated to encounter extraterrestrial thinking creatures, the question of achieving mutual understanding will probably become much more complicated.

In particular, if we believe in the possibility of the development of civilizations (achieving our present level) over hundreds of thousands or millions of years, then it is natural to assume that the carriers of these civilizations would have produced a scientifically developed organization most fully adapated to their living conditions. Human society even now is a "self-organized system," whose development is proceeding even though in part by means of conscious "self-planning". But what would happen when "self-planning" encompasses also the basic features of the structure of the civilization-carriers themselves? This conscious rearrangement of organization can doubtless proceed much more rapidly than evolution based on Darwinian blind natural selection. Why then do we think that in a million years carriers of a higher developed civilization would change less than living creatures on earth, for example, from the Carboniferous Period to our day?

From this point of view, the question of the capability of living and sensing "automata" constructed on completely new (c mpared with ordinary "life") physical principles takes on an unusual aspect. It is customary to say that they will only execute the intentions of their creators. But what if the intention of the creators is to continue their own culture in new conditions? Variations of this approach, incidentally, have already been outlined in the book by I. S. Shklovskiy.

We must sooner recognize as more paradoxical (even though not precluded) a variation in which in a highly developed civilization existing for 100,000 years conservative tendencies in the intentional preservation of the physical nature of its carriers, recognized as an eternal canon of beauty, prevailed. It is altogether of very low probability that this canon in independently developing civilizations would invariably repeat our own.

# PROBLEM OF THE ESSENCE OF LIFE /28

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I am in agreement with several of the starting-points of A. N. Kolmogorov. Here are the statements:

1) somewhere in the unverse life is possible in some other forms unknown to us, and

2) man perhaps can at some time learn how to create life and, possibly, he can use for this material that differs greatly from the material of which living bodies known in nature are constructed.

From these assumptions, it is desirable to attempt to find a definition of life that would not involve data on the chemical composition and structure of bodies unknown to us. Here we have in mind however, that not all that is logically possible can exist. No one has proven that life is possible in a completely different chemical composition than the one which characterizes it in terrestrial reality. It is very difficult for us to imagine life whose basis would not be the physical and chemical properties of proteins and nucleic acids, life that would be intrinsic to systems devoid of water or lacking colloidal-crystalline structure.

In order to imagine living bodies differing essential in /29
chemical composition from the bodies we know, let us assume that in living bodies some element vital to life is replaced by another element chemically similar to it. However close silicon is to carbon, many properties render it unsuited for replacing carbon in living bodies. Let us present only a few examples. The analog of carbon dioxide -- silicon dioxide -- very readily polymerizes and forms a solid. A universal process intrinsic to most living bodies, such as the evolution of carbon dioxide gas due to dissimilation, would be extremely difficult in silicon-containing organisms, since they would release a solid compound upon fermentation and oxidation. Silicon is unsuitable also for constructing many compounds vitally important to life. I do not know whether silicon-containing analogs of purine and pyrimidine bases that are incorporated in nucleic acids could be constructed. In any case, silicon forms even the simplest aromatic compounds with very great difficulty.

It strikes us that this example is sufficient to see that we
are stepping into the realm of purely conjectural constructs when /30

we attempt to discuss concretely the possibility of life with an essentially different chemical composition than the one in which it is familiar to us. It is also logically possible that any life is inevitably a "form of the existence of protein bodies," therefore the question of life with a different chemical composition appears to us somewhat premature, all the more so in that modern biology confronts us with a great many other, more urgent problems.

# WHAT IS MAN?

/31

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Man is a purposefully organized system of atoms, a high form of organization in which matter begins to be aware of itself. Each atom preserves all its properties, manifesting them in complex chains of chemical reactions. Each elementary process proceeds according to laws intrinsic to atoms and molecules, though some of these properties are not manifested in conditions of inanimate nature.

This point of view can often raise objections. But in fact man is constructed of atoms of food, water, and air according to the plan laid down in the DNA of his first cell. Only the information incorporated in these DNA make him distinct from an amoeba or from the reserve of nutrients. But this information is so complicated and purposeful that on its basis such human properties emerge, as systems that differentiate him qualitatively from the animal world, and still more so -- from inanimate nature.

The applicability of the laws of physics to all the processes occurring in man and the fundamental possibility of simulating his thinking processes with artificial systems, and describing these processes in cybernetic terms does not demean him, just as man is not demeaned by the fact that his body is attracted toward the earth, obeys laws of mechanics, and consists of atoms. The collective thought of people by means of books, machines, and other means of communication, the storage and processing of information bears virtually unlimited possibilities, and this is more important than illusory ideas about a nonphysical life force, which are fading away with advances made in knowledge, just as other prejudices of mankind -- geocentrism and anthropomorphism -- have faded away.

/33

# CHAOS AND LIFE

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The well-known British astrophysicist James Jeans, in his book The Universe Around Us, issued in the early 30's in discussing the relationship of life and the universe, wrote: The three centuries elapsing since Gioidano Bruno was burnt at the stake for believing in multiple inhabited worlds have brought with them a description of the world that has undergone nearly no change in our understanding, but they have brought us appreciably closer to understanding the relationship between life and the universe. We can only construct riddles on the significance of life, which we can plainly see, is a very infrequent phenomenon in it. Is it a higher achievement toward which the universe is tending and for which the billions of years of the transformations of matter in uninhabited nebulae and stars and the scattering of radiation into empty expanses is only an improbably strange and astonishing preparation? Or is it not a simple accident and an unimportant side product of natural processes occurring in universal matter? Or, on moving to a more modest point of view, should not we view it as a disease that matter begins to suffer "in its advanced years, when it loses its high temperature and ability to generate the high-frequency radiation with which younger matter could have at once annihilated life?"

Here we have only questions. However, they are phrased so as to express a certain point of view according to which life in the universe is an improbably strange and amazing phenomenon, perhaps an accidental and insignificant product of the development of natural processes or even a disease of ageing matter.

Jeans' conclusions are based on comparing physical conditions encountered in the universe with the conditions in which the existence of living creatures is possible. This comparison shows that the conditions favorable for living creatures are encountered infrequently in the universe and are associated with cooling matter. However, Jeans used only astronomical data and did not bring in necessary information about life itself; biophysical properties of life were still not yet adequately known in his time. But it is precisely biophysical information that compels us to look at the relationship between life and the universe in a quite different fashion.

* * *

Let us first examine how the fundamental laws of nature are refracted in the biophysical properties of life. This examination can serve as starting points of view for generalizations and extrapolations expanding the cosmic significance of life.

Life cannot be reduced to transformations of energy, but is necessarily accompanied by them. If the transformations of energy occurring in organism are halted, it dies. /34

A comparison of this fact with the second law of thermodynamics at once enables us to make several important conclusions.

An organism cannot be a system closed to the influx of energy from its environment. By virtue of the second law of thermodynamics, the internal energy stored in an energetically closed organism passes over into inconvertible forms and the organism's life activity ceases. Therefore all organisms are open to the influx of energy. Plants acquire energy directly from the external physical environment by absorbing light radiation from the sun. Animals acquire free energy by eating other organisms.

However, the capture of energy from the environment by the organism is not a passive process. It requires the active functioning of the organism. One of the most important manifestations of this activity is that in acquiring energy from the environment the organism expands the free energy contained in it and previously stored by it. Therefore only at a high enough reserve of free energy is the persistent existence of an organism possible; the loss or the extreme depletion of this reserve cancels out the possibility of its restoration and therefore are irreversible. Not only the capture, but also the storage in its biomass of an adequately high energy level comprises the constant concern of any organism. In other words, any living body must be a system exhibiting properties of energetic self-regulation, that is, a system which in the conditions of its existence regulates itself and controls its internal store of free energy capable of transformations.

The preservation of the necessary energy level represents a difficult task for plants. The environment where a plant lives is variable. Only in certain states of this environment is the energy of higher sources accessible to plants. By continually using energy, a plant can store only at certain periods of the year that are favorable for this purpose. The required energy balance is not maintained of itself. By intensively enriching itself with energy during the summer time of the year that is favorable for this, a plant vigorously restricts the consumption of energy during the winter period when it has no opportunity of replenishing its energy store. To do this, the plant is compelled /35 to alter its structure and mode of functioning. These changes are reflected even in the outward appearance of plants: it is sufficient to compare the same plant in summer and winter in order to see this. We are accustomed to these changes and do not think about the fact that they are manifestations of the processes of energetic self-regulation of plants without which the preservation of life on earth will be impossible.

The preparation of plants for favorable and unfavorable environmental states proceeds in advance. This is done by the plants being capable of responding not only to direct energy influences of the environment, but also signals of the preceding states of this environment. The ability to respond to signals and to prepare in advance for future environmental states that is useful to plants emerged during evolution and was consolidated by natural selection; it is essential for the preservation of a species in conditions of the not entirely regular inflow of energy into the environment. At the present time it has been found that the principal signals to which plants respond include -- in spring -- the temporal course of temperature in the environment, and -- in autumn -- the length of the sunny part of the day.

Animals and man differ from animals in that for them the capture of free energy from the environment and the preservation of the required energy level represent a much more difficult task.

The responses of animals to environmental phenomena conveying predictive information are much more complex and advanced than plant reactions. In addition to summer reaction such as changes in hair covering, dormancy, and so on, animals respond also by complex forms of behavior (preparation of food stores for the winter, migration of birds, seasonal and other migrations of animals, and so on). Moreover, animals are capable of self-learning and elaborate a system of condition to reflexes reflecting the statistical regularities in the temporal alternation of phenomena in the environment. In the central nerve systems of higher animals, condition reflexes enabling the animals to prepare in advance for a desired response correspond to the phenomena that are precursors of events vital to the life activity and preservation of the species. The ability to generate responses to predictive information is widespread in the animal world. /36

Ultimately, living creatures are able to overcome the enormous resistance of the environment (dictated by the second law of thermodynamics) which is caused by the degradation of energy and of the resistance that is due to the irregularity of the influx of free energy capable of transformations into the environment. However, this does not take place by itself, but is achieved by the appropriate level of organization of living creatures and by a certain, purposeful mode of their functioning. But it is precisely with this aspect of life that the greatest dangers are fraught.

Besides the degradation of energy, a phenomenon that can be called the degradation of the organizational structure of material systems, or more briefly -- organizational degradation -- is of universal importance. Essentially it amounts to the following: if the level of organization of an individual system regarded separately exceeds the organizational level of the environment, then the energy transformations occurring in the system gradually break down the structure of the system and ultimately the breakdown of the system ensues. By allowing ourselves some liberty in phrasing, we can express this thought /37 also by the following: an individual system operating in a chaotic environment or in an environment with an organizational level that is lower than the level of the system itself is doomed, -- by gradually losing structure, after some time the system dissolves into the more chaotic environment surrounding it.

The law of organizational degradation applies not to phenomena of the emergence of organized systems in a chaotic environment, but to their subsequent fate as individual systems that in some manner or other emerged in this environment. Everywhere we observe the emergence of systems with an organizational level exceeding the environmental level: the formation of complex molecules, the formation of crystals, or the birth of living creatures. Organized systems, emerging independently of the law of organizational degradation, thereupon are subject to this law.

Consequently, in contrast to the second law of thermodynamics, the law of organizational degradation does not introduce elements of irreversibility into the development of the world and does not bring about the irreversible disappearance of organized systems in general, though each organized system regarded individually ultimately dissolves into the chaotic medium surrounding it. By virtue of just the law of organizational degradation, the world around us is incapable of being converted into a chaotic world and a medium that is organizationally homogeneous.

The law of organizational degradation is applicable to living systems, and in this sense the death of an organism is a consequence of its vital activity.

Organism losses caused by the breakdown of a structure by the chaotic environment, in contrast to the losses caused by the degradation of energy, are immediately irreplaceable from the environment. Only components essential for the restoration and building of structural formations can be extracted from the environment, but the environment cannot contain these formations in ready form. And we know that each organism renews its tissues from substances it captures in the environment. However, total renewal is impossible, and with increasing wear of an organism, the ability to renew is gradually diminished and ultimately organizational degradation occurs. /38

For an individual organism, overcoming organizational degradation is an insurmountable obstacle, and each living creature ultimately dies. However, for life as a whole constituting a process unfolding in time, this obstacle is surmountable. Reproduction is the method by which life overcomes organizational degradation. As the results of their life activity, organisms of each species produce, before their degradation occurs, new organisms similar to themselves, capable of living and reproducing after the death of their parental individuals. Here not only is the organizational level of a given species transmitted to its progeny and preserved in it, but the progressive evolution of the organizational level is possible in the subsequent change of generations.

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During the years when James Jeans wrote the book referred to at the beginning of this article, new ideas of the place and role of life in nature took shape in fields of science far-removed from astronomy. We have in mind the work of V. I. Vernadskiy dealing with the biosphere, that is, the shell of our planet in which living matter exists and where its influence is manifested. The generalizations of V. I. Vernadskiy that were exceptional in their profundity were presented in two of his essays: "Biosphere in Space" and "Realm of Life," subsequently combined into the book Biosfera /Biosphere/.

After the investigations of V. I. Vernadskiy, it became altogether clear that the biosphere cannot be regarded only as a realm of habitation by living creatures on earth. It is a complex organized system in which various species of animals interact with each other, and all of living matter interacts with its physical environments.

The first and very important conclusion of the V. I. Vernadskiy that opposes the views of Jeans is that life is not a passive and chance phenomenon emerging in the cooling regions of the universe. Life emerges in relatively cold areas of space, however these areas are penetrated by high-frequency radiation of hot bodies of the universe. /39

"Without exaggerating, we can state," writes V. I. Vernadskiy, "that the chemical composition of the external crust of our planet, the biosphere, is entirely under the influence of life and is determined by living organisms. It is doubtless true that the energy that gives the biosphere its usual appearance is of cosmic origin. It emanates from the sun as radiant energy. But it is precisely the living organisms, the totality of life, that convert this cosmic energy into terrestrial, chemical energy and produces the infinite diversity of our world. These living organisms which by their respiration, their nutrition, their metabolism, their death, and their decomposition, by the constant utilization of their material, and importantly -- the continuous change of generations occurring over hundreds of millions of years, along with the birth and reproduction of these organisms have generated one of the most splendid planetary phenomena existing nowhere else than the biosphere. This grand planetary process consists of the migration of chemical elements in the biosphere, the movement of earth atoms, lasting continuously for more than two billion years under specific laws.

... But the manifestation of an individual organism is lost in its surrounding environment. We have to direct our attention at all the existing myriads of living organisms -- the entire totality of life in order to understand the tremendous natural phenomenon that they produce. Everywhere in the environment of life there is the tremendous chemical transformation, the movement of matter, molecular change that is caused by life. We can trace throughout the entire biosphere in this manner the movement of molecules brought about by life; it encompasses the entire troposphere, the entire realm of oceans, and of animate nature on dry land. We can detect its manifestation in the free atmosphere -- in the stratosphere and further up to the outermost limits of /40 the planet. We can demonstrate its influence far beyond the bounds of the realm of life -- in the deep layers of the earth, in the regions of metamorphosis completely alien to us."

The presence of living matter in the biosphere imparts a distinctive appearance to energy phenomena on the earth's surface.

First of all, the living matter in the biosphere accumulates and stores in its biomass energy of solar radiation, by converting it into the energy of organic compounds capable of further transformations. The plant cover of continents and green organisms of the ocean are the entry channel into the biosphere for this energy and represent its main accumulators. Herbivorous plants and predators feeding on other animals serve as channels of secondary transformations and secondary accumulations of free energy in the biosphere.

However, the enrichment of the biosphere with free energy proceeds not only as the result of the accumulation of this energy in the biomass of organisms. When living matter interacts with physical environments (soils, natural waters, and with the atmosphere), there is a continual enrichment of these environments with convertable energy.

Thus, due to living matter the energy of solar radiation does not simply act on the earth's surface, but becomes the energy of the earth itself and of its processes.

The atmosphere itself in its principal gases -- oxygen, nitrogen, and carbon -- is a producer of life. The constancy of the oxygen reserve in the present atmosphere is also a result of the vital activity of plants. Earth organisms pass on during the year masses of gas which exceed by several times the mass of the atmosphere, $6 \cdot 10^{13}$ tons, to sustain their existence.

In addition, as the result of the vital activity of plants, soil is enriched with free energy. This enrichment occurs when plants produce subterranean organic matter, when soil is loosened by the root systems of plants and by water currents penetrating /41
into the soil as the result of the activity of roots, when roots give off chemical substances into the soil, and so on.

The influence of living matter is not limited to the thin film formed by soil, but penetrates much more deeply. In geological time living matter penetrated the earth's crust with very minute dust of its remains and with many minerals formed under the effect of its life activity. As a result, the crust became enriched with free energy.

The trapping of the energy of solar radiation by the biosphere, the transformation of this energy into free energy of living matter, and also the enrichment of the physical environment surrounding living matter with free energy obey the usual laws of thermodynamics operative in energy phenomena. Nonetheless, these laws are insufficient for a scientific understanding and description of the energy phenomena occurring in the biosphere.

Actually, we know that the trapping of solar energy by green plants and its conservation as chemical energy of organic compounds are controlled by signals of the geophysical environment conveying information on the future states of this environment. But signals of the geophysical environment are essential not only in phenomena of primary absorption and accumulation of energy by green plants. No less important a role is played by signals of the geophysical environment also in secondary transformations of energy in the biosphere. The ability of animals to respond to signals of the geophysical environment produces the concord of seasonal development of trophically-associated levels of the biosphere that we see in nature.

Thus, we conclude that the specificity of energy phenomenon in the biosphere is caused not by violations of the laws of thermodynamics, but by the cybernetic properties of the biosphere. The biosphere is an environment in which interaction between energy and information is carried out on a vast scale.

The effect of the information sensed by organisms on energy transformations on the earth's surface imparts specific features to the biosphere. The point is not only that the ability of organisms to respond to information enables living matter to accumulate in their biomass irreversible energy and to enrich the physical environment with this energy, but also that during the course of time, as the biosphere becomes more complex, these phenomena become increasingly more intense. From the energy point of view, the appearance and development of the biosphere on earth -- with its living matter, atmosphere, and soils -- must be viewed as the origin of a grand process of the gradual accumulation of a reserve of convertible energy in the planet's surface layer and thus a reduction in the "production" of irreversible forms of energy in terrestrial nature. /42

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During natural selection, living creatures inhabiting the biosphere, on perfecting their structure and forms of behavior during many centuries, have adapted to the environment. At the same time the living matter of the planet enriched the physical environment of the biosphere with free energy and produced soils and the earth's atmosphere. But apart from soils and atmosphere, present forms of life would be impossible. Therefore, the transfer of free energy to the environment and the regulation of the reserve of this energy in the environment can be regarded as the active production by living matter of conditions favorable to its existence.

In this way, natural selection was not only the motive force of the progressive development of organisms, but also a factor converting the environment into something favorable to life. Life simultaneously adapted to environmental conditions as well as produced this environment. The closed loops of communication between the physical environment and living matter represent the sources of development and self-regulation of the biosphere.

All the foregoing shows how great is the role of natural selection in forming the forces opposing energetic and organizational degradation of nature. However, ultimately natural selection is still climaxed by self-negation: it produces /43 organisms exhibiting a level of organization so that that they go beyond subordination to natural selection; they not so much adapt their structure to the environmental requirements as modify the environment into something favorable to themselves. By outpacing in his development other organisms on earth, mankind reached this stage.

The escape of man from the influence of natural selection has given rise to new phenomena; their study goes beyond the limits of purely biological knowledge. The biological collectivism of organisms grows into a qualitatively new phenomenon -- the social mode of existence of man and the ability of organisms to participate in collective influence on the environment grows, in the case of man, into socially organized labor aimed at utilizing nature and transforming it. The emergence of human society and its specific laws must be viewed as the continuation of processes that in their initial and qualitatively distinct forms were born and matured in the early depths of the biological stage of development. From this point of view, the emergence on our planet of human society is just as predictable as the emergence of the biosphere.

But it is very important to note that the passage of man from natural selection bears enormous consequences not only for man in himself, but also for his natural setting. The biosphere, on becoming an object of the socially organized labor of man, develops no longer so much under the influence of elemental selection as much as the result of the rational and directed activity of human society. Here it is natural to expect changes so significant in the realm of life on our planet that one must speak of the transformation of the biosphere into a qualitatively new shell of the earth -- the biotechnosphere.

The time has arrived when nature transformed by man and technical devices influencing it merge into a single integrated system. Beginning with the transformation of nature, mankind is proceeding to its organization and ultimately will produce a fundamentally new earth shell consisting of a physical environment, its populating organisms, and incorporating in nature technical devices controlling the physical environment and to a large extent producing it. And whatever are the laws of the development of the technosphere, one thing is clear -- the process of the enrichment of the planet's surface with free energy not only retains its significance, but will progressively grow in significance. /44

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From the foregoing it is clear that the principal sources of the resistance of the environment to organisms were its following properties: degradation of energy, degradation of organizational structure, and inconstancy of the influx of free energy. Let us agree to call the environment in which these phenomena take place a chaosogenic environment.

The structure of organisms, the mode of their influence on the environment, and adaptive of evolution were mainly directed at overcoming the difficulties generated by the chaosogenicity of the environment. Only at the level of the biological form of the motion of matter was nature able to create systems capable of existing in the chaosogenic environment with a stability ensuring self-reproduction.

What we have said provides an idea only of one aspect of the effect that the chaosogenicity of the environment exerts on life. There is yet another, more profound aspect to this question, which as far as we know has not been an object of philosophical or scientific scrutiny.

The persistent existence and functioning of any system is possible only when the level of organization in the system corresponds to environmental conditions. This level must be sufficient for a given environment, but must not be excessive. We must not /45 suppose that the higher the level of organization in a system, the more it is adapted to the environment. An overly high level of organization unwarranted by environmental conditions diminishes the adaptability of a system to exist in the given environment, while an overly great superfluity of organization renders the existence of the system impossible in the environment.

On applying this general principle to animate nature, we must once again recall the uncommonly intricate and multi-faceted adaptivity of living creatures to the chaosogenic environment. The high level of organization, finding its expression in the structure of organisms and the mode of their functioning, was literally fashioned by this environment. In any less complex environment such a high level of organization would be superfluous. Therefore organisms cannot emerge and live in an environment free of energy degradation and not subject to the law of the dissolution of organized systems into the chaotic environment; if they are placed in such an environment, they will lose their viability doomed by the superfluity of organization. In this case the complexity of structure and perfection in behavior become superfluous and useless qualities. On being freed of the pressure of the chaosogenic environment, life dies as a deep-water fish expelled to the surface of the ocean and ruptured by its internal pressure, which is its adaptation for equalizing the pressure of the enormous weight of water.

The results of analyzing living creatures as energy-cybernetic systems, combined with analysis of the relationships of living creatures with their environment, can be formulated as follows: the resistance of the environment dictated by the second law of thermodynamics, by the "law of dissolution" of organized systems into the chaotic environment, and the nonregularity of the influx of free energy is at once an obstacle overcome by living creatures and a mandatory condition for the emergence and existence of organisms.

This is the dialectics of the relationship of life phenomena /46
with the laws of degradation. Life is the negation (in the dialectic sense) of the second law of thermodynamics and the law of the dissolution of organized systems in the chaotic environment. And at the same time the existence of the environment governed by these laws is a prerequisite for the emergence of life and its progressive developments.

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The relationships of living matter with the physical environment and the fundamental laws controlling this environment provided us with certain indications as to the place and possible significance of life in the universe.

We cannot doubt that chaosogenic conditions do exist in the universe: we ourselves live in them. But we are not in a position to answer the question as to whether the entire universe is chaosogenic or only some realms of it.

An attempt to represent the entire universe as chaosogenic gives us a one-sided, imperfect, and logically closed picture of the cosmos in which all transformations of energy lead to its degeneration, to the irreversible transition of free energy into an irreversible form scattered in space. On the other hand, we have no empirical grounds for the hypothesis that in the universe such anti-chaosogenic realms exist in which there would be reversible processes: the condensation of dissipated degraded energy and its transformation into free energy. The principles of physics also do not provide concepts dealing with the possible nature of these realms or even indications that they exist.

This difficulty is hardly coincidental. We can present the following consideration on the epistemiological basis of this difficulty. Let us assume that the universe is a combination of chaosogenic and anti-chaosogenic realms. At the same time
the emergence and development of life, including thinking crea- /47
tures, is possible only in a chaosogenic environment. Therefore all the experience of living creatures, and thus also the experience in human perception of the external world, and possibly

also the logic of our thinking about it bear the impress of the limitations that stem from the fact that interactions only with a chaosogenic environment are accessible to life. We do not wish by this to state that anti-chaosogenic realms are unknowable. Though anti-chaosogenic realms of the universe cannot be an object of immediate perception for living creatures, still if these realms exist, then inevitably they interact in some manner with chaosogenic realms; and by the effects of these interactions, information about them can be obtained indirectly. However this is a fundamentally different avenue of cognition based on interpreting only secondary phenomena and associated with overcoming certain obstacles. It is possible that it is precisely these circumstances that account for the deep-rooted notion of the chaosogenicity of the entire universe.

Whatever status, however, chaosogenicity occupies in the universe, the appearance of life in its chaosogenic realms represents not an accidental phenomenon, but the predictable result of the development of matter. The simplest initial forms of the organization of matter emerged already during the physical stage of development. Nuclear and molecular forces are the principal organizing factors in the microcosmos. Then deep within the chaosogenic regions of the macrocosmos organized systems emerged, exhibiting cybernetic properties and capable of preserving stability by equalizing influence of the environment and by adapting to it. From these, by means of selection and evolution life grew and became perfected. The chaosogenic environment regularly engenders its dialectical negation -- living systems overcoming the chaosogenicity of the universe.

It may be that modern scientific thought, by vigorously preserving the traditions of caution, nonetheless must become bolder in evaluating the place of life in the universe. On emerging independently in many parts of the universe, in its /48 chaosogenic realms, life becomes distributed in it. And is the thought that the emergence of life in the chaosogenic realms of the universe denies the birth of a new stage of development of the universe really so foolish? It may be that life, especially its higher forms, is destined to become an organizer of the universe by vigorously enlarging and entrenching the realm of its propagation. This though appears to us extreme, evidently on the same grounds by which a prophetic thought that man will be an organizer of nature on the scale of the entire planet would strike our ancestors, living only one or two thousand years ago, as extreme.

But if we leave to one side the assumptions of the possible significance of life in the further development of the universe and base ourselves on the foundation of reliable knowledge, then we still would be deeply erroneous to speak about the phenomena of life as a disease of ageing matter. What Jeans called the ageing of matter, that is, the loss of high temperature and the ability to generate high-frequency radiation, is a result of the accumulation of the effects of the second law of thermodynamics. We know that it is precisely in the conditions produced by this law that life emerged and develops. However, if life were a disease of ageing matter, then like any disease associated with senility, it must intensify decay and ageing, that is, it must deepen the manifestation of the second law of thermodynamics, and accelerate the conversion of free energy into irreversible forms. But all that we know of life at the present time speaks to us that the reverse has occurred. Life, predictably emerging in the chaosogenic realms of the universe and overcoming the enormous resistance of the chaotic environment, slows down and weakens the conversion of free energy into irreversible matter. Therefore if we seek for a symbolic expression of the function performed by life, a picturesque description of its objective role in the universe, then we must speak of life not as "a disease of ageing matter," but of the "courage of matter."

We have allowed ourselves to use expressions such as "disease of ageing matter" and "courage of matter," though these are not scientific terms, but more properly, poetic images. However, not /49 only signs and symbols of science and abstract concept, but also even poetic images can be carriers of cognitive information. Poetry is also thinking, and thus is capable of supplementing science in its most difficult and profound questions.

A figurative characteristic such as "courage of matter" or "courage of nature" is worthy of life not only for the resistance put up by living creatures to chaosogenic phenomena in their environment, but also owing to their internal qualities. In spite of the fact that existence is the higher subjective value of all living creatures, in them lies the ability to be concerned about maintaining life as a whole and preserving its place in nature with greater force than the concern to preserve the individual existence. This is achieved by reflecting objective expediency in the subjective qualities, desires, and behavior of living creatures. In confirmation of this we can cite the well-known ability of man and animals to sacrifice themselves in defense of their progeny. In the instances when the progeny of a given species does not need the concerns of its parental organisms, the immediate predictable death of the living creature is possible after it has provided for the reproduction of these species. For example, many insects die after depositing eggs, while some species of fish die after spawning. This obviously indicates that that is programed into the organism.

Death, accompanied by the transfer to the progeny of useful qualities and the coded information in the appropriate manner, is useful to life as a whole as a phenomenon unfolding in time, since it opens up the broad prospects of the perfection of life in the course of development.

If by the laws of nature life was destined to overcome the consequences of the chaosogenic phenomena of reality, then we must regard any bearer of this process emerging within the depths of life itself as an abnormality, as a pathological inconsistency with the ongoing purpose and meaning of life. Unworthy are the lives of living creatures who, aware of the cosmic significance of life and not striving to fulfill it, do not weaken by their existence and their activity the chaosogenicity of reality, but rather intensify it. Any weakening of life: the unleashing of wars, the suppression of mankind by hunger and poverty, the unwillingness to improve nature and human society -- deserve the severest censure not only from the sociopolitical point of view, but also from the scientific point of view.

# LIFE CANNOT BE AN ACCIDENT /34

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(United States)

A characteristic of living systems is a high degree of order, much higher than in any of the inanimate systems we know of. Even the simplest living organisms are extremely complicated. On turning to the scale of ordered structures, we can see that the distance between the bacterium and man is much shorter than -- for example -- between the bacterium and a giant electronic brain. With the ordinary course of events, order shows a tendency to diminish; therefore it is not easy to understand how life can emerge from inanimate precursors. Several explanations of this have been proposed, but none can serve as an object of scientific investigation. Among the hypotheses deserving of scientific discussion, the most attractive is the hypothesis that inanimate components took on configurations compatible with life as the result of some happy accident. For any configuration to be compatible with life, it must combine capacity for metabolic activity with stability, and even with adaptability. Moreover, it must have the ability to reproduce itself from the individual /35
components present in the environment. These are requirements that are hard to satisfy. In order to evaluate their significance properly, let us inquire into what appears to us to be the critical stage in the origin of life. Suppose we have a "thick, heated, salty broth" containing various organic molecules -- amino acids, sugars, polyphosphates, pyrimidines, purines, and so on. What is the probability of an event occurring in which some fortuitous configuration of these molecules will prove to be compatible with life?

The total number of cases in which life can emerge as the result of creative acts is equal to the product of the number of different sections suitable for this to happen and the number of cases when this event could have occurred. The number of sections is equal to the ratio of the total suitable volume to the volume which the components of the future structures must satisfy (we will neglect here the overlapping of components). The upper limit to the total volume will be assumed to be the entire surface of the earth ($5 \cdot 10^{18}$ cm$^2$) covered with a layer of water 1 m thick, that is, $5 \cdot 10^{20}$ cm$^3$). Of course, the minimum volume of the set of components must not be less than the volume of a bacterium, that is, $1 \cdot 10^{-12}$ cm$^3$. Thus, the number of suitable /36
sections cannot exceed $5 \cdot 10^{32}$.

To get the lower limit, let us assume that the interface at which ordering can occur will be only the ocean coast. Suppose the shoreline has a length of $5 \cdot 10^{10}$ cm, that is, it can girdle the globe roughly ten times. Let us assume that the dimensions of the elementary volume do not exceed 1 cm in either direction; This value can scarcely be somewhat larger if the components of the future system must encounter each other rapidly enough due to diffusion. The number of sections obtained is $5 \cdot 10^{10}$. Thus, we find that the number of sections suitable for the chance formation of living structures lies between $5 \cdot 10^{10}$ and $5 \cdot 10^{32}$.

The time interval during which in the "thick, hot, salty broth" containing as many potentially suitable 'building blocks' as we wish life could have emerged must be estimated at about $2 \cdot 10^{9}$ years, or $2 \cdot 10^{13}$ hours. The time allocated for a single "creative act" is limited, on the one hand, by the rate of formation of macromolecules and more complicated structures, and on the other -- by how long the incomplete structures can exist, awaiting possible culmination. This minimum time, of course, can never be shorter than a single hour, that is, the time required for -- in moderately favorable conditions -- one bacterium to be formed from another. The upper limit can be taken as the time exceeding this value by the factor of $10^{10}$, which agrees with the rough estimate of the ratio of the reaction rate when enzymatic catalysis is present, to its rate in the absence of this kind of catalysis. Hence it follows that in each suitable section the number of cases favorable for the act of creation (as a result of which some system with the principal characteristics of life could have emerged) ranges from $2 \cdot 10^{3}$ to $2 \cdot 10^{13}$. By multiplying the number of sections (from $5 \cdot 10^{10}$ to $5 \cdot 10^{32}$) by the number of cases (from $2 \cdot 10^{3}$ to $2 \cdot 10^{13}$), we get the result that the total number of cases that could lead to the origin of life lies between $10^{14}$ (the product of the two lower estimates) and $10^{46}$ (the product of the two upper estimates), with a precision for each integral limit of several orders of magnitude. Obviously, the task of narrowing this enormous interval -- extending over more than 30 orders -- must not encounter serious difficulties; however, for our purposes it is not necessary to solve this problem. It suffices to state any event of this type of which we are speaking must occur if its probability is higher than $10^{-10}$, and must not occur (or must occur not more than once) if its probability is smaller than $10^{-50}$. /37 /38

A considerably overstated estimate of the number of cases in which the "building blocks" (organic molecules) could unite and form a living structure is $10^{46}$. A very understated estimate of the volume of essential information in a simple living organism considered as an ordered system of the same blocks is 1000 bits, corresponding to a probability of $10^{-301}$. Therefore, the probability of life emerging as a result of the random occurrence of any of these $10^{46}$ events is approximately $10^{-255}$. If we use a higher estimate of the volume of information, the desired probability will be correspondingly reduced. From the extreme smallness of this quantity follows the actual impossibility of the appearance of life resulting from the chance union of molecules. The assumption that a living structure may have emerged through a single act due to the chance union of molecules must be rejected. Of course, even an event that is impossible in actuality can occur once, but it cannot occur more than once.

Hence it follows that if life had emerged in this extremely improbable manner, then undoubtedly it would not be on earth or anywhere in space that any other form of life, of another origin, could exist. If life of extraterrestrial origin is found on Mars, then this finding will refute the origin of life as a result of the chance union of molecules. In any case, it appears more promising to search for a mechanism that would not provide for such incredibly improbable events. /39

# LIFE IN THE COLD OF "SPACE"

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Can plants live at superlow temperatures? What happens in the plant cell in this situation?

The French scientist P. Becquerel was the first to attempt to answer these questions. He cooled dry seeds nearly to absolute zero, and then from them he grew completely normal plants. But the seeds more readily withstand the severities of life, being reliably protected by their natural cases. Could adult plants pass this test? And, moreover, Becquerel was still unable to find out what takes place within plants in severe cold. /40

For a long time no one knew why the trunk of a tree and its branches can withstand winter temperatures down to -40° C, while the roots die even at -15° C. Evidently, the reason must be sought for in the fact that the roots live in the ground and therefore are less adapted to cold. But what specifically interferes with roots from becoming just as inured as the above-ground section of the tree? This problem was of special interest to us since we had long been working on the frost resistance of plants.

First we somewhat exposed roots, leaving their upper section in the air. Next, the roots were coated with louver-shields and in the winter the plant was exposed to cold -- natural and artificial; for this purpose, we had field chilling stands. It turned out that tree branches became more cold-resistant, while the roots as before remained sensitive to cold.

Then we somewhat modified the experiment: the louver-shields were removed and the tree was frozen again. And once again it withstood the cold splendidly. So it was natural to assume that constant "blowing" of the roots and also exposure to light inures roots and increases the general frost-resistance of a plant. In this way we found what is necessary to inure a plant. But we /41 did not yet know what happens in it at the cellular level. And this was quite essential to know since otherwise the experiments described would remain still curious observations.

We found that in autumn when the days become shorter special substances accumulate in plants -- so-called growth inhibitors, retarding growth. The mechanism of the action of these substances remains thus far unclear, but it is obvious that they prepare the plant for winter cold. We tried to isolate the inhibitors and to spray plants with them and succeeded. The tree at once stopped growing. Plainly, this phenomenon can be utilized later on a broader scale.

During the growth retardation period in autumn, plants strenuously accumulate sugar. Why? It turns out that it is needed by plants as a kind of "additive" lowering the freezing point of water within cells. Summing up all the observations, we were able to develop laboratory methods of increasing the frost resistance of plants.

After these experiments, it was of interest to find what is the lowest temperature that plants can tolerate if they have been inured by our method -- by being successively brought through an /42 artificially shortened day to allow them the opportunity and time to accumulate sugar. We took several cuttings of black currant inured with our method and began to gradually lower the temperature -- at the rate of 1/10-th of a degree per hour. In this way the temperature was brought down to $-60^{\circ}$ C. Then, the main part of the experiment commenced: the plants were immersed in liquid nitrogen, whose temperature is $-195^{\circ}$. Next, the black currant cuttings were withdrawn from the chilling stand and gradually began to thaw. And in a few days we saw how branches that had been in the cold of "space" at a temperature of $-250^{\circ}$ sprouted green leaves.

Then we cooled other inured plants down to $-253^{\circ}$ and the result was exactly the same: the plants did not die. I do not doubt that with this method plants can be cooled even to absolute zero and life will again triumph.

These experiments enable us to conclude the following: there are two ways of obtaining nonfreezing plants. The first is by means of gradual dehydration, when water leaves a cell and passes into the intercellular void and ice cannot form within /43 the cell. Strictly speaking, this method is what nature selects. And the second way is the method to which the experiments led us and which we used in cooling black currant down to superlow temperatures. In this case the plant is chilled so fast that the water is unable to be converted into ice. It becomes an increasingly unique substance resembling glass. Molecules become consolidate in this "glass", freezing in place, in contrast to ice, whose crystals resembling sharp wedge rupture the tender cell walls. It is precisely this property of water that assisted the young shoots of wheat in our experiments to cope excellently with a temperature of $-195^{\circ}$.

The experiments with superlow temperatures enabled us to penetrate the functioning of the highly delicate mechanism that

frost-resistant plants possess. Thus far, only the most general concepts of the operation of this mechanism have been named. It was found that when a plant is prepared for winter, processes occur in cells resulting in a change in the physiological state of the protoplasm. And the contents of a living cell -- formerly liquid -- become gel-like or like jelly. This jelly renders the protoplasm more resistant to mechanical deformations and dehydra- /44
tion and the cell does not fear the cold: the cell contents remain unfrozen in the frozen plant.

Of course, preparing a plant for freezing with all the stages during which "jelly" forms within the cells is possible only in the laboratory, but sometimes this can also be done in practice: it is sufficient to spray the plant with the growth inhibitor -- and it winters splendidly; it may be even thus in conditions of "outer space" frosts.

Such experiments with superlow temperatures were also conducted in Japan. But there scientists worked with plants that had been taken from the out-of-doors in winter when they had been prepared for the experiments by nature herself. But we took our plants in May, when even 5 to 7° below zero suffices to kill a plant, and brought the plants successfully through all stages of preparation to the cold of "space". Moreover, we were the first to suggest a theory that affords the possibility of explaining in detail the phenomena occurring in plants at superlow temperatures. We learned that this gel-like state of the protoplasm is the main "trick" of a plant.

## DISCOVERY IN ETERNAL ICE-FIELDS

/45

In Queen Maude Land Soviet scientists discovered insects smaller than 0.5 mm in size. They inhabit lichens and rock mosses on the northern slopes of mountains. These insects resemble arthropod or primitive wingless insects and have -- in contrast to this type -- spread over other continents and have not three, but four pairs of legs.

The finds were of interest not only to zoologists, but also to astrobiologists. Indeed, the unusual fact that living organisms have adapted to the protracted conditions of very low below-zero temperatures can modify views on the possibility of life existing on other planets..

## PUZZLE OF THE BLUE-GREEN ALGAE

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Experts visiting an island in the Pacific contaminated after the blast of an American hydrogen bomb saw that blue-green algae grew on fused radioactive rocks. These plants are amazing in their viability; they are found on the highest peaks of the Pamirs and on the slopes of a volcano after its eruption. They apparently represent the climax of the biochemical development of life. /46

Plants carrying out photosynthesis stand higher than the animal world biochemically.

Blue-green algae depend on nothing other than themselves: they assimilate the sun's energy and fixate air nitrogen. The following experiment was conducted. Several representatives of the animate world at different degrees of biochemical development were placed in glass spheres -- small animals and plants. The spheres were filled with water and sealed. A closed ecological system was produced, where upon exposure to the sun the cycling of matter occurred. In several years it ceased, and only the blue-green algae remained in the spheres: they proved to be the best adapted in the struggle for life.

Planets with a water and gaseous shell are evidently also ecological systems. It is possible that something resembling blue-green algae exists there. Of course, this is a hypothesis but space flights will be able to test it.

## WE NEED NOT NECESSARILY HAVE HAPPENED /47

A. A. Neyfakh, Doctor of Biological Sciences

The appearance among animals in the course of evolution of what we call reason is an acquisition so useful to a species that it at once (in the evolutionary scale of time) began to dominate even over the entire planet and even went beyond its bounds. Still, life appeared about three to four billion years ago, while rational life -- not more than a million years ago. We are correct in questioning why rational life did not arise earlier if its appearance was actual so inevitable, as is often stated. We cannot state that this is related to changes in physical conditions on earth -- they did not change so far as to preclude the appearance of rational life, for example, 200 million years ago. It can be said that the emergence of rational life required certain preliminary stages of evolution to have taken place -- the development of multicellular animals, the separation of functions between their organs, formation of a nervous system, formation of hand-type extremities, and so on.

But all these stages have been passed quite long ago, evidently about half a billion years ago. Cannot we then assume that in nature there is only one pathway for the development of rational life -- through the chordates to the mammals, primates, /48
and to man. Nothing other remains for us than to admit that this tortuous pathway of the evolution of reason was fortuitous in large path and not obligatory. We can quite readily imagine ourselves a planet where there are no animals at all and life will evolve without passing beyond the scope of plants. Recall that mammals -- our ancestors -- were a minor group for nearly a hundred million years (the Mezozoic Era) with advantages that were not evident. And, possibly, if the giant lizards had not perished, even today Mezozoic fauna would be flourishing on earth.

Finally, in discussing the last stage of our evolution it is naturally to quite seriously repeat a familiar childhood question: why did not all the apes want to become people? We now explain the actual appearance of apes as an adaptation to the conditions of the tropical forest, but the appearance of erect walking and the emancipation of the hands as an adaptation to the disappearance of the forest. How little, obviously, did the geographic conditions on earth have to differ from those then prevalent for this disappearance of the forest not to have occurred and for apes to have not been compelled to descend to the ground.

# LIMITS OF LIFE /50

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Life can be characterized as a combination of a specific material substrate and energy processes essential for metabolism, which differ from mass exchange in inorganic nature by its self-regulation and by the fact that in the living organism biochemical processes counteract the dissipation of energy (entropy). Underlying the structure of all living systems known to science are complex molecules, or biopolymers, consisting of proteins, nucleic acids, and carbohydrates. In addition, even simpler compounds are incorporated in living creatures, for example, phosphorus compounds, water, and a number of other elements. Thus far no scientifically reliable model of life on a different basis has been forthcoming. Characteristics of the molecular and cellular structure of life and its functions differ qualitatively from the structure of the inanimate substrate, though at some stages of evolution a transition occurred from inanimate organic matter to the formation of a living system. Therefore, we can speak of the limits demarcating a living system from an inanimate system.

Our task, in relation to the problem of life in space, is to find the limits of life determining in which environmental conditions organisms can exist. If we take as a model of life the organisms inhabiting the earth, we must establish which conditions limit their existence. At the present time a specialized science has emerged -- exobiology (or astrobiology), which deals with problems concerning life outside the earth. Research in this area is underway in the USSR and abroad. We will discuss investigations conducted in the Institute of Cytology of the USSR Academy of Sciences.

Primarily, living creatures need conditions in which they can trap energy for their vital activity and acquire substances for building complex organic molecules. Here physical and chemical factors of the environment play a most vital role, especially temperature, which above all determines the limits of existence for life. The role of this factor has been studied quite closely.

The upper temperature limits of life are determined relatively simply. With temperature rise, evaporation causes intensified loss of water without which the fundamental biochemical processes and metabolism cannot occur. At a sufficiently high temperature (usually above 40-50°) the activity of enzymes is upset, breakdown of protein complexes begins, and physicochemical phenomena referred to by the name denaturation and coagulation commence. However, lower organisms are encountered that have adapted to life in hot springs at a temperature of 70-90°. Temperatures above the boiling point of water are tolerated only by spores and certain other resting species containing almost no water. /51

The limits of life at low temperatures are less well-defined and their study poses great difficulties. If we are interested in the minimum temperature at which a living system can preserve its viability, that is, can avoid being subjected to irreversible breakdown and following a temperature rise, begin to function normally, then we have a clear answer to this question -- this temperature is at about absolute zero.

It has long been established that some lower organisms tolerate drying and cooling at any low temperatures. It was shown later that among so highly organized animals like insects there are species that withstand freezing. A remarkable example is the wintering larvae of the corn borer, which can tolerate a temperature of -196 and -269° in a frozen state, as hard as crystal, without drying out. The cells and organs of vertebrate animals preserved in glycerin and certain other substances (ethylene glycol and dimethylsulfoxide) can be kept indefinitely long at these superlow temperatures, even though some of the water in their bodies is converted into ice. After thawing, they prove to be viable, capable of growth and acclimatization. In deep chilling metabolism is absent in living systems; they are in a state of anabiosis. Can the cells and organisms in this state be regarded as living?

If we turn to the specific phenomena of life on earth, then we see that with the onset of unfavorable conditions associated with seasonal changes in climate, many animals fall into winter sleep. They undergo an interruption in the development of their active functioning; metabolism is reduced to a minimum; body cells become resistant to cold; and the organism acquires the ability to withstand very low temperatures and sometimes even freezing. The temporary depression of metabolism is widespread; it has adaptive significance. In this relative anabiosis, certain mammals, for example, gophers, survive even at body temperatures below zero. Their cells are in a supercooled state. In invertebrate animals, the temperature of body fluids can be many degrees below their freezing point. The ability to undergo supercooling, exhibited by animals subjected to low temperatures in nature, is one of the important forms of cold adaptation. Limits to supercooling in insects, based on our observations, are about 50-60° below zero for certain species.

Thus, the cessation of active functioning is not in contradiction to the concept of life, but only supplements our ideas of life. The ability of living systems in unfavorable environmental conditions to pass over into the state of rest and anabiosis tremendously broadens the limits of life and the possibilities of its propagation in the universe. But the temperature limits at which propagation, development, development, and evolution of organisms are observed are much narrower. Only the most highly organized animals which in the course of evolution acquired a high body temperature and advanced thermal regulation (homeothermy) have to some extent become independent of low temperatures on earth. For all other organisms, temperatures somewhat below zero are a barrier to active life -- the animals pass into the state of torpor. Still, even in the severest conditions on earth life exists: in the zone of perpetual snow in the high-mountain regions, on arctic islands, on the Antarctic continent, and in polar bodies of water where life flourishes at temperatures from $0^{o}$ to $-2^{o}$. /52

Recently we investigated a unique phenomenon of nature -- the section of permafrost on Mount Razvalka in the Northern Caucasus formed as a result of the eruption of cold gas from deep within the earth. At temperatures from $0^{o}$ to $-1.5^{o}$, many species of worms, mollusks, ticks and mites, springtails, and other small insects develop in depressions of the soil and limestone. Springtails -- tiny wingless insects adapted to life in the snow -- are active at temperatures somewhat below $0^{o}$, and among flies, mosquitoes, and moths are found species that fly and mate during frosts (from $-8^{o}$ to $-10^{o}$).

On earth most organisms need oxygen for energy processes; its concentration in the atmosphere is sufficient for higher organisms and exceeds the oxygen demand in invertebrate animals and in plants. When the oxygen content in air is one-tenth of the normal value, insects develop quite normally. Experiments showed that cardiac and motor activity ceases in insects only when the oxygen concentration in the atmosphere drops to 1.0-0.8 percent (normally, air contains 21 percent oxygen). In insects living in mountains at an elevation of 3200 m, heart beats stop only when atmospheric pressure drops to 5 mm Hg, when the amount of oxygen reaches 0.2-0.1 percent. But among various groups of invertebrates and one-celled organisms there are species that require an even smaller amount of oxygen or can exist in anaerobic /53
conditions.

As shown by our studies, the simplest animals -- the infusoria -- can multiply in a nitrogen atmosphere containing only 0.0005 percent oxygen, given the condition of the continuous replenishment of the gaseous environment. The total disappearence of oxygen causes the death of infusoria just as it does for other animals. Therefore, these one-celled organisms can extract the gas they need to perform energy metabolism even if only traces of the gas are in their environment. A low atmospheric pressure, down to the limits of 5-3 mm Hg, only slightly reduces the vital activity of the protozoa. It is remarkable that the same infusoria, and also many bacterial species can develop in an atmosphere containing 98-99 percent carbon dioxide gas, but when its partial pressure is very low, approximately between 15-70 mm Hg. In other words, an atmosphere similar to that on Mars is not an obstacle for life in several organisms.

Thus, there are no adequate grounds to assume that, for example, the low oxygen content in the Martian atmosphere is a barrier to the existence of organisms on Mars.

Among the physical factors which organisms can be subjected to beyond the limits of the earth's atmosphere, in space the most important is ionizing and short-wave ultraviolet radiation. It is at present difficult to state how much radiation emitted by the sun limits the existence of life in space. This is accounted for by the fact that given the unconditionally intense destructive effect of these kinds of radiation, especially hazardous to higher organisms, fluctuations in sensitivity to these radiations are very large in various species. Sensitivity depends on the stage of development, physiological state of the organism, composition of chemical compounds, content of nuclei acids in cells, and several other cell characteristics as yet unknown. While there organisms and cells that die after exposure to ionizing radiation at doses of several hundreds and tens of roentgens, the /54 protozoa -- for example, the infusoria -- tolerate up to half a million roentgens, and euglenids -- up to 1.8 million roentgens. The even greater persistence of certain protozoa and bacteria is indicated.

A widely-held view maintains that short-wave ultraviolet radiation kills off microorganisms in space and life is impossible on planets where ultraviolet rays are not absorbed by an ozone screen. At the present time we can scarcely speak of this so categorically. Screens can exist and even do exist in organisms themselves, not admitting short ultraviolet rays, for example, certain plant pigments and protective substances attenuating the action of these rays. It is possible that chitin is one such screening substance found in the body integumenta of insects and a number of extinct protozoans. This is indicated by our experiments subjected to many hours of irradiation with ultraviolet rays at high intensities without any damage.

We presented a number of examples dealing with factors restricting the existence of life in a state of depressed metabolism and anabiosis, as well as during active functioning. However, to determine resistance to a given kind of exposure it is not enough to find the survival rate of a given group of organisms. Life in fact differs from nonlife by having capabilities of adapting to new, unusual conditions. Moreover, on the example of the ability of earth organisms and cells to tolerate conditions they have not encountered in nature -- temperatures close to absolute zero, vacuum, high doses of ionizing and short-wave ultraviolet radiations -- clearly shows that life has a high margin of "strength". Therefore it is natural to assume that living systems, whose model can be taken as earth organisms, are capable of existing under conditions other than those on earth.

The question arises: how does life "protect itself" against extremal influences, that is, those to which it has not been adapted during evolution, and at what level of organization is maximum resistance achieved? In this respect, the effect of various influences on biopolymers and their constituent linkages was investigated. It can be assumed that the stability of the structures and functions of cells hinges on the stability of biomacromolecules, for example, nucleic acids, nucleoproteins, and proteins. Experimental studies showed that one cannot give an unequivocal answer. For instance, as a result of freezing of chemically pure proteins and nucleoproteins even at a temperature not very low, such as $-10^{\circ}$, significant changes occur in the biopolymers, partially precipitating out. Still, this temperature is entirely innocuous for many cells and organisms. Their high stability in this case can depend on two causes: the presence in cells of protective substances blocking the breakdown of biopolymers, or the ability of living systems to recover from damage. In some cases the recovery can occur in the biopolymers per se outside the organism. /55

Biopolymers have greater resistance to ultraviolet and ionizing radiations than do cells. Outside the organism their destruction requires irradiation with enormous doses, while in the organism changes occur in biopolymers at doses several orders weaker.

In the broad spectrum of ultraviolet solar rays, the most dangerous for cells is the short-wave region, particularly near 254 nm, selectively absorbed by nucleic acids, desoxyribonucleic proteins (DNP) -- the most important material in the cell nucleus -- and by proteins. At high radiation doses, beginning at $0.5 \cdot 10^8$ erg/cm$^2$ and higher these rays change the viscosity, molecular weight, and other properties of DNP.

Cells irradiated even with relatively small doses of short-wave ultraviolet rays, for example, $6 \cdot 10^5$ erg/cm$^2$, perish not only due to the disruption of nucleic acid synthesis, but also due to damage to the fine structures and disturbance of metabolism. /56

We studied the ability of cells to recover after being irradiated with ultraviolet rays and the presence in organisms of protective substances and structures blocking the selective absorption of these rays. If after irradiation with a dose causing death when carried out in darkness cells are exposed to visible rays, they not only do not succumb, but not even delays in division occur in the cells -- the phenomenon of photo-reactivation.

It is entirely possible that on earth before the formation in the atmosphere of the ozone layer blocking short-wave ultraviolet radiation from the earth's surface, organisms contained enzymes of the cytochrome or other types exhibiting the ability to even better restore cells after damaged caused by ultraviolet rays than the enzymes in present organisms.

Therefore it is not wholly correct to speak about the limits of life based on the conditions on earth and the adaptations to these conditions shown by now-present organisms. However, study of the process of adapting to extremal influences at different levels of life's organization brings us closer to understanding the causes determining the limits of life. Adaptation is possible even to such an unusual damaging influence like short-wave ultraviolet radiation. Thus, if paramecium infusoria are subjected to repeated irradiation with weakly damaging doses, after which they recover, in the future they will tolerate even doses that had previously been lethal.

The ability of life to regulate its functions and to restore them after damaged caused by extremal influences is the physiological basis for the adaptation of organisms to new environmental conditions.

Thus, for example, paramecium infusoria regulate the rate of /57
reproduction, which as we know depends on temperature: the lower it is, the fewer the cell divisions in a day. However, it was found that if the temperature is varied daily from $22^{\circ}$ during the day to $10^{\circ}$ at night so that the mean-diurnal temperature is $16^{\circ}$, the infusoria apparently do not respond to the lower temperature ($10^{\circ}$) and multiply at a rate corresponding to an apparent mean temperature of $22^{\circ}$.

The restoration of damage is strongly affected by external conditions. Let us present an example. After being cooled down to $-78^{\circ}$, wintering larvae of the corn borer usually remained alive for many weeks and even months, but did not metamorphose into pupae, though we placed them in a temperature setting optimal for development ($22$-$24^{\circ}$). But when larvae thawing after freezing were placed for a month in a refrigerator, and thereupon at the optimal temperature, nearly all larvae pupated rapidly, and fertile moths were hatched from the pupae. Obviously, the restoration proceeds better at a temperature close to $0^{\circ}$ than at $22^{\circ}$.

In the course of evolution, as a result of adaptation to seasonal changes in climate, organisms acquired high cold resistance. The degree of cold resistance is affected by the environmental temperature in the autumn-winter period or by the conditions of cold-hardening in nature and in experimentation. In a great many organisms, both plant and animal, cold-hardening is carried out most effectively upon prolonged exposure of cells to temperatures somewhat above $0^{\circ}$.

But the survival rate of organisms in their cells during freezing is especially strongly affected by the cooling rate and the warming, or thawing rate.

The highest survival rate in yeasts, protozoa, and insects was achieved when we used a mean cooling rate of several degrees per minute. Until the cells reached maximum cold-hardiness, they are best cooled stepwise: first to $-30^{\circ}$, and then to $-78^{\circ}$ and below. Active noncold-hardened earthworms -- nematodes -- best withstood the temperature of $-196^{\circ}$, if they were placed in these conditions at once and succumbed when slow cooling was used.

The warming rate can have an effect even greater than the rate of cooling. The highest survival rate was attained for yeasts, nematodes, and insects we investigated with the fastest possible warming rate, achieved by immersing the frozen specimens in boiling water.

Lacking the opportunity to highlight in detail correlations as unexpected as these, we point out that the survival rate of cells and organisms during freezing depends on the nature of the water of crystallization -- the form and size of crystals forming inside and outside of cells, and the nature of crystallization is affected by the rates of cooling and warming. Owing to other physiological features of cells of higher plants, as we know from the literature when deep cooling is used is observed when very slow cooling and just as slow warming are employed.

In the case of irradiation, its duration (time factor) and dose intensity are of vital importance. For instance, if infusoria are subjected to ultraviolet irradiation all at once or if the action of the same dose is stretched out over several hours, wholly different effects result. In prolonged irradiation, when a cell observes less energy per unit time, it is unable to recover; after repeated short-term irradiation the recovery process proceeds more smoothly. /58

These examples show how diverse are the conditions on which the limits of the existence of life depend. This problem becomes even further complicated if we take note that in nature an organism is subjected to a multitude of influences and their complex is not the simple sum of the constituent natural factors. We can present many examples showing that the response of cells and organisms to ionizing and ultraviolet radiations is dissimilar in different conditions of temperature, illumination, moisture content of environment, and for different gas compositions. In the event that oxygen is absent in the environment and there is a reduction in the amount of water in the organism, the effect of ionizing radiation is diminished.

In the Northern Caucasus we found paramecium infusoria living in a hot radioactive spring, which proved to be more resistant to ionizing radiation, high temperature, and several chemicals compared with infusoria of the same species from a nearby ordinary body of water.

It is possible that the "secret" in the change in resistance upon the influence of the complex of factors for cells lies in the nature of changes in the structure of biomacromolecules. Thus, the photochemical action of ultraviolet rays differs when DNP is irradiated in the liquid state at ordinary temperature from when it is irradiated when frozen at $-78^{\circ}$. More severe changes in this case occur in frozen solutions. For the "crosslinking" of a minute chain of macromolecules ruptured by freezing, an entire order higher of ultraviolet ray energy is required than for "crosslinking" in solution. Breaks in the chain occurred at a higher radiation dose, while "crosslinking" occurred when the solution was again irradiated with a smaller dose. The ionizing radiation (gamma-rays) caused greater changes in the DNP when a solution was irradiated than for irradiation in the frozen state, but the action of ultraviolet rays on biological materials can be more intense when they are frozen. Accumulation of this kind of data enables us to approach an understanding of the limits to the existence of the most important "building blocks" of life in conditions of irradiation and cooling.

Finally, we cannot afford to pass over a vital condition for the existence of life. Nature differs from the laboratory in that in nature conditions are continuously changing and for this reason the limits of life depend on the degree of adaptation of life to the environment, for example, to such cosmic effects as diurnal, seasonal, and other changes in climate. To determine the limits of life, experiments on simulating extremal conditions on earth and those existing on Mars are of great interest. As an example, we present one of our studies with the colpoda infusoria.

These microscopic one-celled animals living in soil were subjected to gradual drying, as a result of which they ceased to move and multiply and were coated with a thick crust forming a resting cyst. Then they were kept at $-78^{\circ}$ (in some experiments, down to $-196^{\circ}$) for several hours. Next, the environment was warmed and /59 from the cysts emerged vigorously swimming infusoria, which began multiplying with a temperature rise. The experiment showed that the entire developmental cycle in these conditions can be set up in Martian days (close to 24 hours), but with each subsequent cycle the infusoria become fewer. Therefore, Martian conditions proved to be not entirely favorable for this species, which could in fact have been expected. In later experiments the times between repeated freezings and dryings were extended to 48 hours; when this was done, the active lifespan was prolonged to 27 hours. As a result, the number of infusoria did not decrease, but rather rose by tenfold due to intensified multiplication. Experiments with cooling were conducted also in an ordinary atmosphere and in a rarefied atmosphere, whose pressure was lower than on Mars.

Further investigations will show what earth organisms can be acclimatized in Martian conditions. Science is gathering, year by year, more and more facts indicating that life can occur in altogether uncommon conditions. The limits of life are being ever-extended, and special efforts and experiments are needed to gain a fuller idea of the essentials of life. Research on the distribution and conditions for the existence of organisms on earth not only has not been concluded, but it appears to us is entering a new phase.

Thus far, regions unfavorable to life for most organisms on earth have been given little study, for example: the depths of the earth, ocean deeps, life on the Antarctic continent, on ice-fields and beneath ice, in caverns and subterranean lakes, in bodies of water with special chemical composition and thermal conditions, with various levels of radioactivity, and so on.

Another avenue of the investigation of the limits of life is study of the possibilities of organisms multiplying and developing in various environmental conditions produced artificially, regulated, and varying according to a set program. Numerous experiments set up in special chambers in which the climate of the planet Mars is simulated showed that a long series of bacteria, yeasts, algae, and even primitive animals and higher plants can exist in the gas regime, atmospheric pressure, low humidity, and low temperatures that are known to occur on Mars. But it is true that this is only the start of work in this highly promising direction.

## ON THE BORDERLINE BETWEEN THE LIVING AND THE DEAD /52

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Academy of Medical Sciences

Study of the nature and reproduction of viruses poses anew the problem of the material carriers of life. The familiar formulation of Engels' about life as a form of the existence of protein bodies, which sums up our knowledge of life reached at the end of the last century, requires a re-examination in the light of data from molecular biology and virology accumulated already at the beginning of this century.

Actually, upon study of the mechanism of viral reproduction it was found that the initial stage of this process culminates with the penetration of the virus into a cell and the freeing of viral nucleic acid from its protein sheaths. And it is precisely viral nucleic acid that interacts with the cell, bringing a series of specific syntheses, climaxing in the formation of virions (mature viral individuals). Since all the genetic information is coded in the viral nucleic acid, for many viruses it has been found possible to reproduce the complete cycle of reproduction by infecting a cell with purified viral nucleic acid. Thus, at a certain stage of its development the virus is "naked" nuclei acid deprived of its protein sheaths, which is valid for all /53 viruses.

But the situation is not restricted to this. We know of at least one virus -- lipovirus, which even at the mature stage (in the virion stage) does not include proteins in its composition or else negligible amounts. As follows from the name, lipovirus virions consist of nucleic acid enclosed in a protective lipoid sheath. Finally, several viruses can exist not at a particular stage, but more or less continually in a state in which they are naked nucleic acid deprived of protein sheaths, usually combined with the cell's nucleic acid. Evidently, phages exist in this form in the lysogenic cell of bacteria, as do oncogenic viruses in neoplastically transformed cells.

These concepts of viruses served as starting data for reexamining Engels' formulation. They made it possible to define life as a special form of the existence of organic matter, whose main substrates are nucleic acids, proteins, and organophosphorus compounds. The essence of life lies in the quantitative and qualitative increase in genetic information as a measure of the order /54 and complexity of organisms. In this sense, life is the expression of the unity of contradictions between environmental entropy and the information of living organisms. Storers of information are the nucleic acids, with whose appearance primitive forms of the existence of organic matter associated with proteins began to inevitably and irreversibly to develop from lower forms to higher forms under the influence of environmental conditions and obeying the law of natural selection.

With the appearance of man and human society, life reached its highest form, since the further rise in information is now related not with genetic information, but principally to the thinking activity of man and the development of human society.

There are two parts to this definition, one which applies to the material substrates of life, and the other -- to the principal essence of its manifestations. We note that similar attempts at defining life were made as long ago as the mid-1930's.

But let us turn to nonprotein stages of the forms of life represented by viruses, whose existence apparently reflects the above-expressed principle of the three main substrates of life /55
-- nucleic acids, proteins, and organophosphorus compounds. Actually, this is not so because viruses are obligate intracellular parasites, whose biosynthetic processes are to a large extent provided for by the cells where they parasitize.

Outside cells, viruses are metabolically inert and their existence over a particular segment of their reproduction cycle or in a specific state in the form of naked nucleic acid assumes that they are found in the protein medium of the host cell.

It then takes onto itself the forced concern of protecting the fragile thread of alien nucleic acid and ensuring the expression of the genetic code embodied in it.

Our knowledge of nucleic acids, these chemically active biological polymers, renders of low probability the assumption that they can exist in an external medium as unprotected proteins or lipids. On the other hand, dressed in protein or lipid sheaths, nucleic acids are biologically inert.

Only within the host-cell is this contradiction resolved, since it is precisely here that there are structures ensuring the /56
possibility of the preservation of the integrity of the nucleic acid and the possibility of expressing the genetic code its embodies.

Thus, viruses or specific stages of their development can only provisionally be classified as nonprotein forms of life since the existence of the nucleic forms or stages of viral development presupposes the manifestation of vital activity in the protein medium surrounding them.

## IS "NONPROTEIN" LIFE POSSIBLE?

V. G. Fesenkov, Academician

In the universe, organic life -- if it exists in general -- can be constructed on the basis of carbohydrate compounds.

Therefore, any kind of notion that life can be built up from other elements, for example, that the role of carbon can be exercised by silicon, also a tetravalent element, but vastly rarer, with entirely different properties -- all this must be recognized as groundless fantasy.

# FIRST STEPS OF EVOLUTION /60

A. G. Vologodin, Corresponding Member of the USSR Academy of Sciences

Based on geological data, backed by absolute geochronology, we know that the origin of the simplest forms of life -- archeobionts and protobionts -- occurred evidently 3.6-3.0 billion years ago, since an age of 2.7 billion years before our era already characterizes several discoveries of the remains of multicellular blue-green algae (for example, in the region of Krivoy Rog in the Ukraine, in deposits of the Transvaal series of the South African Precambrian), accompanied by clearly bacterial formations. The organic remains were there found to be represented by clusters of carbonate and graphitic material in the form of formations of various shapes. Therefore, the upper limit to the formation of the first forms of life must now be "shifted" into the past beyond the limits of 3.0 billion years.

Following next, based on the data of absolute chronology, we can regard the discoveries of organic remains in the strata of the Belomorskaya series in the Kola Peninsula, in the Lower Proterozoic of Karelia (in the strata of the Ladoga series). They are represented by fairly well-shaped one-celled species, sheathed and unsheathed, and also by remains of ciliated algae. Of much interest are the discoveries by D. Hall, J. Matthew, and C. Walcott in the strata of the North American Precambrian, represented by the so-called stromatoliths and other forms in which the vital activity of microscopic blue-green algae was manifested. In recent years, similar work has been continued by E. Barghoorn, P. E. Claude, W. Shopf, and others. These investigators studied silaceous formations aged about 2.0 billion years from the region of Lake Superior near the boundary of Canada and the United States and found interesting remains of one-celled forms and ciliated algae.

In the USSR efforts to find remains of organisms in Precambrian rocks have proven even more successful. Particularly interesting in this respect are the regions of Karelia and Kola Peninsula, where the Lower and Middle Proterozoic is broadly developed. It was now possible to add to the former discoveries of, within neighboring Finland, remains of Coricium enigmaticum Sederholm the same formations from the area of the Northwest Ladoga Region accompanied by a mass of organismic remains, among whom have been found representatives of spongoids, medusoids, and also remains of blue-green and other algae.

The Lower Proterozoic of the Soviet Union is still very poorly explored with respect to organic remains. Even differentiating rocks of sedimentary origin often runs into difficulties owing to their high metamorphism. Moreover, volcanogenic-tufogenic formations predominate in its composition, both on the Kola Peninsula and in the Ukraine, as well as most mountainous areas of Siberia. Organic life of aqueous environment at that time was still represented predominantly by one-celled forms, indicated by the bac- /61
terial structure of jaspilite iron ores and the pyritization of sandstones and quartzites. The world of microorganisms was already active even on land, where it brought about an intensive breakdown of bedrock with the formation of melkozem /fine earth/. The latter showed up more effectively in direct proximity to algae producing free oxygen. But all told, conditions stimulating the development of anaerobic (nonoxygen) forms of life predominated.

The author has been able to find in the conglomerates of the top of the Krivoy Rog series of the Ukrainian Precambrian (with an absolute age of not less than 2.0 billion years!) remains of an alga described by the name Protospira ukrainica Vologdin (Fig. 1), very reminiscent to the present freshwater alga Spirogyra. Other remains of organisms not yet adequately studied were also found. Remains of algae were found also within the limits of the Moldavian Dniester area. Particularly interesting are the remains of organisms in the strata of the Lower Proterozoic of the Northwestern Ladoga Region in Karelia (near the city of Sortavala). An intricate complex of organismic remains was found in the black crystalline schists of the Ladoga series, whose composition thus far has been described as including representatives of blue-green algae -- Ptilophyton makarovae Vologdin, P. ovale Vologdin, and spongoids -- Ladogaella variabilis Vologdin (Fig. 2).

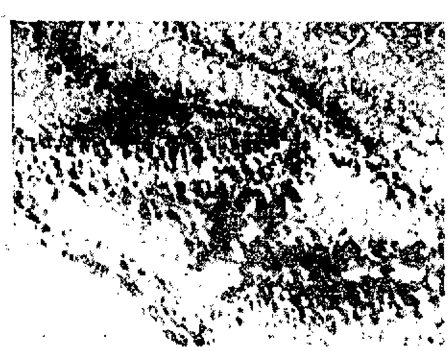

Fig. 1. Remains of alga found in the Precambrian strata (age not less than 2.0 billion years)

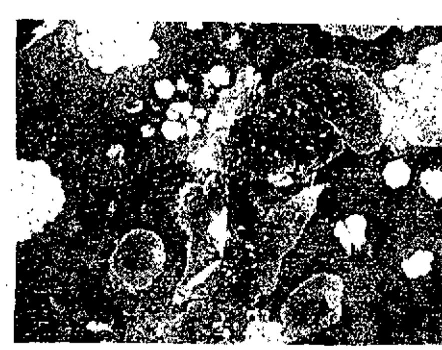

Fig. 2. Remains of the most ancient spongoid organisms

The biosphere in the Early and Middle Proterozoic was still anaerobic. Therefore in the diagnosis of the sediments, iron and manganese accumulated only in the lower valency forms. We know that present ferrobacteria are represented by species capable of displaying vital activity in various temperature ranges: from 1 to 2° C, from 15 to 16° C, and so on. Thus far it is impossible to judge which of the species of ferrobacteria have been found in that remote geological past. Analysis of the isotopic composition for oxygen and sulfur in the future will probably resolve this question.

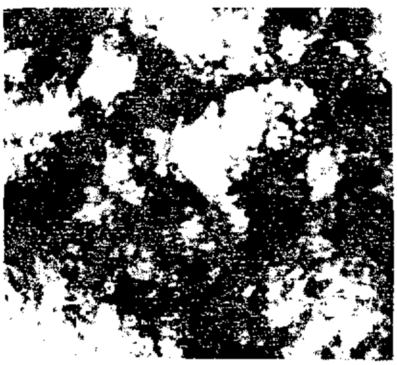

Fig. 3. Remains of foraminferae

The Middle and Upper Proterozoic, nearly everywhere it surfaces, is characterized by a more appreciable participation in its makeup of sedimentary rock, especially carbonate, clearly associated with marine type basins, embayments, and lagoons. /62

Already three horizons containing remains of rock-forming algae have been unearthed in Karelia, in the Onega series of the Proterozoic. Rocks of all three horizons are the most authentic fossil marine reefs, unquestionably formed in normal marine conditions. The distinctive rocks familiar in Karelia, marked by a high carbon content -- the schungites -- can be associated with ancient bitumen formation using the material of phytoplankton.

Nearly everywhere in the world, the Proterozoic is expressed by intense development in its composition of normal marine beds, in part lagoon beds, with the manifestation in places of sedimentary iron mineralization in the form of brown iron ore of bacterial origin.

In the Precambrian deposits, remains of organisms in the Upper Proterozoic (mainly algae) proved to be very common, though investigators have been unable to discover the characteristics of their morphology and biochemistry. Remains of microfauna typified by the skeletons of radiolaria, foraminiferae, spicules of sponges, impressions of polychaeta worms, hydromedusae, representatives of crustaceans, and so on have also been isolated.

Remains of diverse algae were found in the Proterozoic formations of Karelia, among whom we can assume there are even the ancestral forms of corralinacae, remains of the lower crustaceans resembling ostracods but differing in the enormous size of the claws, and a good many other organic remains.

In the most ancient strata of Sudet in Poland and in the area of the Czech massif in western Czechoslovakia, several dozens of deposits of organic remains have been discovered, classified roughly in the Middle and Upper Proterozoic. It is essential to note that the strata of the Pilzen region are heavily saturated in places with residual organic matter, to some extent converted to bitumens and in the graphitized form. Several dozens of algae accompanied by remains of foraminiferae (Fig. 3), brachyoid organisms, and even cephaloids have been isolated from the organisms here.

The Verkhnemorsk Proterozoic in the area of Northern Eurasia was found to be everywhere very rich in the remains of organisms, chiefly algae. In several regions of the Far East of the USSR, fossil algae evidently played a major role in producing organic matter, partially preserved in beds and partially involved in /63 forming petroleum and gas fields. More than 80 species belonging to a number of families and orders are classified in the Late Precambrian.

The massive development of stromatolithic carbonate rocks long not attracting serious attention from paleontologists has been established in the Late Proterozoic beds in places in North America, Asia, Australia, and in Central and Northwest Africa. These formations have been recognized as possible products of the vital activity of algae, but were usually studied only as to external form (conical, cylindrical, spheroidal, and so on). Still, using transparent sections and large magnifications even in certain types of compact carbonate rocks investigators have been able to detect a vast diversity of remains of microscopic algae (Fig. 4), mainly blue-green and less often red.

The rock-forming of certain algae was enormous in some places. In the conditions of shoals and foldings of the earth's crust, they developed with the formation of carbonate suites up to 2000--3000 m thick with an annual bedding of 0.1-0.2 mm.

It has been possible to set the annual cyclicity of their beddings (Fig. 5) in the form of 11 beddings per cycle, enabling us to calculate the lifespan of certain species of algae. A comparison of the biomass volumes of present blue-green algae during a season of vegetation with the Late Proterozoic time showed a considerable similarity. From this we can conclude that in the last 1.5 billion years, solar radiation has not shown an appreciable decline.

Fig. 4. Remains of microscopic algae (Upper Proterozoic)

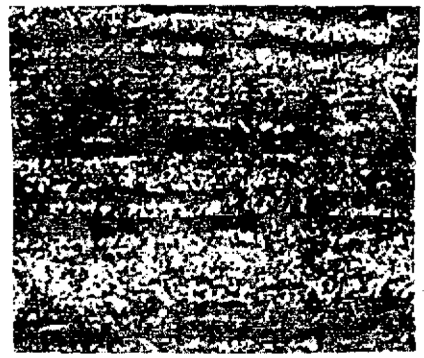

Fig. 5. Cyclic beds laid by the rock-forming activity of the most ancient algae

In terrigenic rocks, but with the same geological age as the Late Proterozoic, remains of various invertebrate animals were found in recent years. In particular, in 1965 impressions of primitive coelenterates -- Hydrozoa from the order of bruxellides /64 -- Sajanella arshanica Vologdin -- was found in Upper Sayan. The remains of chelicerids of the order Prohelicerata Stormer (1944) -- Iyaia sajanica Vologdin, Caragassia karassevi Vologdin, and Ikeyia tumida Vologdin, marked by enormous size, were found in the same area, at the settlement of Arshan, Tulunskiy Rayon, Irkutskaya Oblast. They were confined to strata whose age was set at 640 million years. Worms of the family Sabellidae and hard-to-determine algae accompanied these shell-bearing organisms. Today nearly no geological formations are encountered in which fossilized bacterialike bodies 0.5-1.0 microns in size cannot be found. They can be observed only under the microscope at a magnification of 1500 and higher.

During the general course of research on geological formations, unfortunately as yet little attention has been given to geological microbiology. Still, as early as the 1920's B. L. Isachenko in the Geology Committee of the All-Union Council of People's Commissariats conducted experiments on the role of microorganisms in geological processes.

In efforts to find traces of bacterial activity in the remote geological past, they have been detected not only in the rocks of the Paleozoa, but also in the rocks of the Precambrian. Thus, distinct bacterial structures fossilized with iron oxides were detected in iron ores of the Kola Peninsula and Krivoy Rog.

Essentially, this was the discovery of ferrobacteria of Lower Proterozoic Age. Similar structures were also found in a number of other areas in the USSR (Kazakhstan and Eastern Siberia). Stratal iron ores of the Kursk-Voronezh Magnetic Anomaly doubtless are also of bacterial origin. Interestingly, about 5 percent organic matter of the bitumen type is present in the Swedish iron ores of the Kurinawara deposit; this amount is so constant that it figures even in the economics of the metallurgical process.

Pyrite inclusions are uncommon Proterozoic deposits, comprising clastic rocks. Sometimes these rocks are observed in extensive development over large areas and they can be understood only as sediments of basins with hydrogen sulfide bacterial contamination, developing on dissolved sulfates. In the same way, accumulations of gypsum and calcite in ancient beds indicate the activity of ancient bacteria.

As early as 1923, P. A. Pravoslavlev directed close attention to the question of the origin of "nemic" marine oozes, recognizing them as formations of bacterial origin. The above-noted studies by B. L. Isachenko on denitrifying bacteria of Lake Sevan, there accomplishing the deposition of limestone ooze with the release into the environment of free nitrogen, completely brought to light the primary conditions for the formation of carbonate ooze in seas and oceans in different geological times.

It must be noted that the composition not only of the Archaean but also the Catarchean, in particular, in the Kola Peninsula and Eastern Sayan, the Khamar-Daban Range, the Anabarskiy Massif, and so on have been found to contain marble. In some modifications of intensely marblized Precambrian limestones, carburized bodies of bacterial form and dimensions were found in thin transparent sections under the microscope; these possibly belong to bacteria responsible for the development of the carbonate deposits.

In the Late Precambrian and Paleozoic bauxites, the iron component was everywhere incorporated into bacterial structures.

Thus, it turned out that sedimentary formations of the Precambrian abound in bacterial remains. As we know, investigators of fossil spores detected often complexes of sporelike forms in these rocks. And frequently their forms were similar to the protozoans. Thus, B. V. Timofeyev in 1966 found a great diversity of sporelike remnants in strata of the most ancient

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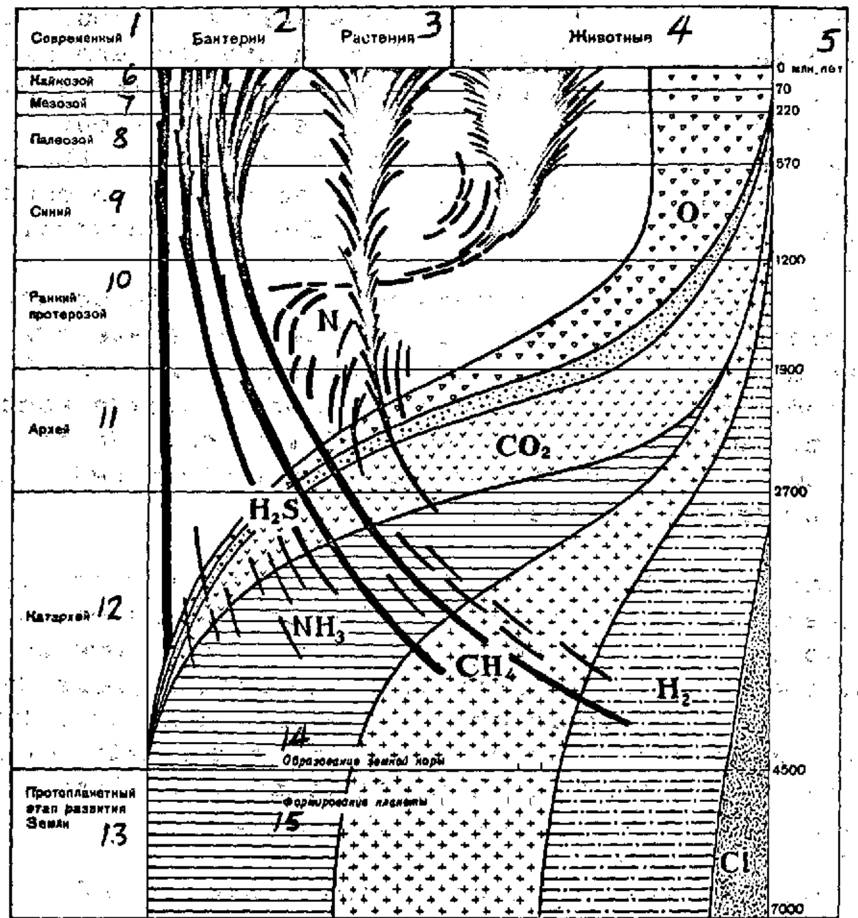


Fig. 6. Evolution of environment and life on earth.

KEY: 1 -- Recent
2 -- Bacteria
3 -- Plants
4 -- Animals
5 -- millions of years
6 -- Cenozoic
7 -- Mesozoic
8 -- Paleozoic
9 -- Blue /Sinyy/
10 -- Early Proterozoic
11 -- Archean
12 -- Catarchean
13 -- Protoplanetary stage of the earth's development
14 -- Formation of crust
15 -- Formation of planet

sedimentary formations. Though the true nature of these formations has not been completely deciphered, the complex of organismic remains found is of great interest. /66

Since the earth's primordial atmosphere was a mixture of gases (evidently, hydrogen, carbon dioxide, methane, and ammonia), present autotrophic bacteria -- hydrogen, methane, propane, nitrogen, and so on -- utilizing these gases as energy sources must be regarded as extremely ancient. Growing on components of the primordial atmosphere, these bacteria even in the Archean time were able to give up into the biosphere reserves of complex carbon compounds, which on being transformed into bitumens in many areas provided and still provide commercial petroleum and gas deposits over large regions, in some locales with large reserves of these minerals.

The primordial earth autotrophes probably were coevals of the primordial bacteria, since the composition of chlorophyll is not more complicated than that of proteins and nucleic acids of closely related types. Paleontological indications that algae developed in the Precambrian are very extensive. Stromatoliths and oncoliths, distinctive calcareous bodies, often abounding in the most ancient carbonate beds prove upon closest study to be products of the microscopic blue-green algae. These algae began their rock-forming geological activity as early as the Archean, that is, about 2.65-2.7 billion years ago.

Let us present several results.

Based on field exploratory data, it can be noted that the Precambrian strata of the crust often indicate the absence of concentrations of sesquioxides of iron and manganese, that is, the abence in the primordial biosphere of reserves of free oxygen. At the same time, a relatively high degree of disintegration and local differentiation of the matter in crustal bedrock is observed. Often this is expressed in the formation of quartzite-like sandstones, clay schists and clays, later transformed into crystalline schists comprising minerals of aluminosilicate composition. This is inconceivable without the concept of the active development of soil and soil-biological processes at land outcroppings.

Along with the remnants of algae in Late Proterozoic beds, in some areas remains of radiolaria, foraminfera, sponges, polychaeta, archeocyathea, brachyopods, and the most ancient representatives of the crustaceans are found.

Finds of so-called charnia in Precambrian beds in England and Australia, classified as possible corals, and also discoveries of xenusion in Proterozoic beds in Sweden categorically contradicts the views of some investigators that there are no shell-bearing organisms at so remote a geological time.

The boundary between the Precambrian and the Cambrian still does not appear to be as well-defined with respect to traces of organic life as appeared even quite recently, and as is stressed by several researchers even today.

It bears noting that material accumulating on the history of the development of organic life in Precambrian times today covers a vast time range. At this stage, the forms of organic life either preserved their initial microscopic and submicroscopic /67
dimensions (the world of bacteria) or displayed an ability to form multicelled organisms with the simultaneous acquisition of relatively larger sizes.

Summing up the material on the development of organisms on earth in the remote geological past, the author attempted to reflect this process in a graph showing the stages of time on the same scale and showing the general trend of the evolution of the three main divisions of living matter on our planet -- bacteria, plants, and animals (Fig. 6). All things considered, life on earth emerged about 3.5 billion years ago. It arose as the result of natural processes transforming the main components of the primordial atmosphere in contact with the mineral matter of the earth, and emerged initially in the most minute forms of life.

# TRACES OF LIFE IN PRECAMBRIAN STRATA AND THE SEARCH FOR LIFE IN SPACE /68

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(United States)

The classical approach toward understanding the evolutionary history of the earth was the investigation of fossil remains, where morphologically recognizable creatures could be ranked in the chronological sequence outlining the pathway of evolutionary development from the earliest times. This was in part the method adopted even by Darwin.

In a certain period of the geological past, about 600 million years ago, morphological remains actually disappeared at the beginning of the Precambrian. Nowadays, with an increase in our biochemical knowledge and with the emergence of analytical procedures enabling us to describe in the most minute detail the subtle molecular architecture of individual molecules, a way has been found out of this impasse. Efforts to find traces of life in the earliest epoch of the earth's history are continuing not only at the morphological, but also at the molecular level. This method, now adopted by organic geochemists, is used to prove the existence of forms of life in Precambrian sedimentary rock estimated at 3 billion years in age. The application of criteria suitable for finding Precambrian rock to the search for life in space is only a logical extension of the method.

The method of organic geochemists is founded on the following prerequisites: some molecules exhibiting a characteristic structural skeleton are quite resistant to breakdown over prolonged periods of geological time. The specificity of their structure is due to already known biosynthetic processes. But the probability of their formation resulting from nonbiological processes is negligible. These compounds are usually called biological landmarks or chemical fossils. Here we must seek compounds that are typical for the living organisms contemporary with us: nuclei acids, proteins, amino acids, organic pigments, carbohydrates, and lipoids. They all satisfy the requirement of structural specificity, but only lipoids, and to a smaller extent, the class of organic pigments like porphyrins, are able to have survived, as we can judge from their initial structural form.

Among the lipoids, a proof that life existed in the Precambrian is regarded as the presence of a group of hydrocarbons, whose structure is based on the isoprene residue $C_5H_8$. This includes, in particular, two specific hydrocarbons: phytane, deriving -- as is assumed -- from the phytole section of a side chain in the chlorophyll molecule, and pristane, also deriving from phytole and present in marine organisms; they were sought for in Precambrian deposits. Their structural scheme, characterized by a /69 single methyl group $CH_3$ for each four carbon atoms, remains stable over prolonged periods of time; moreover, there is no convincing proof that these hydrocarbons could have been formed nonbiologically.

New methods were developed to isolate and identify specific organic compounds present in deposits, and existing methods were modified, enabling them to be applied to small amounts of material.

External surfaces of a rock are cut off to remove gross impurities. The remaining part is washed in solvents and ground. A ground sample is extracted with organic solvent to extract soluble organic matter from it. The extracted organic matter is divided into fractions, ordinarily acidic, alkaline, and neutral; this is done in a chromatographic column in which different classes of compounds pass through an absorbent at different rates.

The fractions thus prepared can be divided (sometimes after chemical transformation into appropriate derivatives) into individual small fractions by passing them through a gas-liquid chromatograph. In the gas-liquid chromatograph, the mixture of compounds -- converted into vapor and mixed with a carrier gas -- comes into contact with a specific liquid on an inert substrate. Based on the nature and structure of the compounds they are dissolved in this liquid to differing degrees. Since a jet of carrier gas passes successively through several sections containing an absorbing liquid, then obviously these mixture components will traverse these sections at different speeds. If several different liquids with different absorbing properties are used, ultimately we can separate individual compounds in pure form.

Individual compounds thus prepared can be subjected to various spectrographic determinations: for example, infrared, ultraviolet, and optical spectroscopy, and also spectroscopy based on nuclear magnetic resonance and mass spectroscopy. The quantities obtained for these purposes are small -- from 50-75 to 1-2 micrograms. Mass spectroscopy is the most convenient method for these tiny amounts. A sample is ionized and its molecules are cleaved into fragments. The mass distribution of these fragments is specific and constitutes a "fingerprint" of the given compound. Recently, it has been found possible to combine gas chromatography with mass spectroscopy, but linking the two instruments so that compounds exiting from the chromatograph enter directly into the ionization chamber of the mass spectrometer and need not be collected separately.

During all operations one must very carefully see to it that contamination of the extracts is avoided. Laboratory dust and skin oils (for example, from the fingers) are typical substances easily causing contamination. Careful work and frequent control experiments show that contamination can be avoided.

We investigated a fair number of geological samples to determine their content of organic compounds. As stated above, special attention was given to polyisoprene compounds. In our laboratory, /70
we examined several Precambrian samples, the oldest of which was taken from a schist deposit in the state of Minnesota. We were able to prove the presence in this sample of several acyclic isoprenoids, including pristane and phytane. Moreover, there is good evidence of the presence of steranes and triterpanes -- they are based data of gas chromatography and mass spectrography.

Isoprenoids were found in numerous geological samples, for instance, in a petroleum sample from Australia (200 million years) and a petroleum sample from the state of Michigan (1 billion years). We also studied several samples of "young" schists. Many cyclic isoprenoids were found in the Antrim schist from Michigan (300 million years). Not only acyclic isoprenoids, but also steranes were found in schists from Green River in Colorado (52 million years) after careful investigation. Recently, this same schist was shown to contain a specific sterane -- gamma-cerane.

Barghoorn et al. has done much to establish -- with an electronic microscope -- that organisms are present in Precambrian beds.

These workers provided excellent proof that these organisms exist in deposits from Gunflint (1 billion years) and from Bitter Springs in Australia (1.2 billion years). They reported on similar finds in a formation in Swaziland in Africa. Organogeochemical results were confirmed by micropaleontological evidence of recognizable morphological remains.

There are reports that biological material has been detected in meteorites. It was reported that they were found to contain amino acids, porphyrins, and isoprenoids. The presence of these compounds in many cases can be regarded as indisputable, though their origin is as yet unclear.

Any geochemical method of analyzing ancient deposits attempting to discover traces of life in the most ancient geological epoch must be evaluated from two vantage points: the reliability of the experimental proof secured and the significance of the conclusions drawn from this proof. The chance of contamination is a constant threat to experimental results. Usually very small amounts of hydrocarbons are obtained from Precambrian systems. As shown, some hydrocarbons, including pristane and phytane, are present in laboratory dust samples, in the oils of fingers, and in pure solvents. And they are present in the same amounts as in Precambrian systems. Though this problem is a constant threat to the experimenter, it is not hard to eliminate by resorting to certain precautions. It is harder -- especially in the case of meteorites -- to control the history of a specimen before it reaches the laboratory. Many meteorites have been exposed to earth organisms when they flew through the earth's atmosphere or when they lay unprotected on museum shelves. This indeterminacy eliminates the significance of findings and leaves the question of life in the universe unanswered.

Finally, if we are dealing with experiments, we cannot overestimate the importance of an exact determination of the "fossil" molecules using all analytical devices available to us. In most cases the amounts we have to work with are so small that only gas chromatography and mass spectrometry can be used. Still, if experimental determinations are inexact, the conclusions based thereon can prove to be altogether incorrect. Actually, an indisputable identification of isoprenoid hydrocarbons is the main prerequisite on which further discussion is based.

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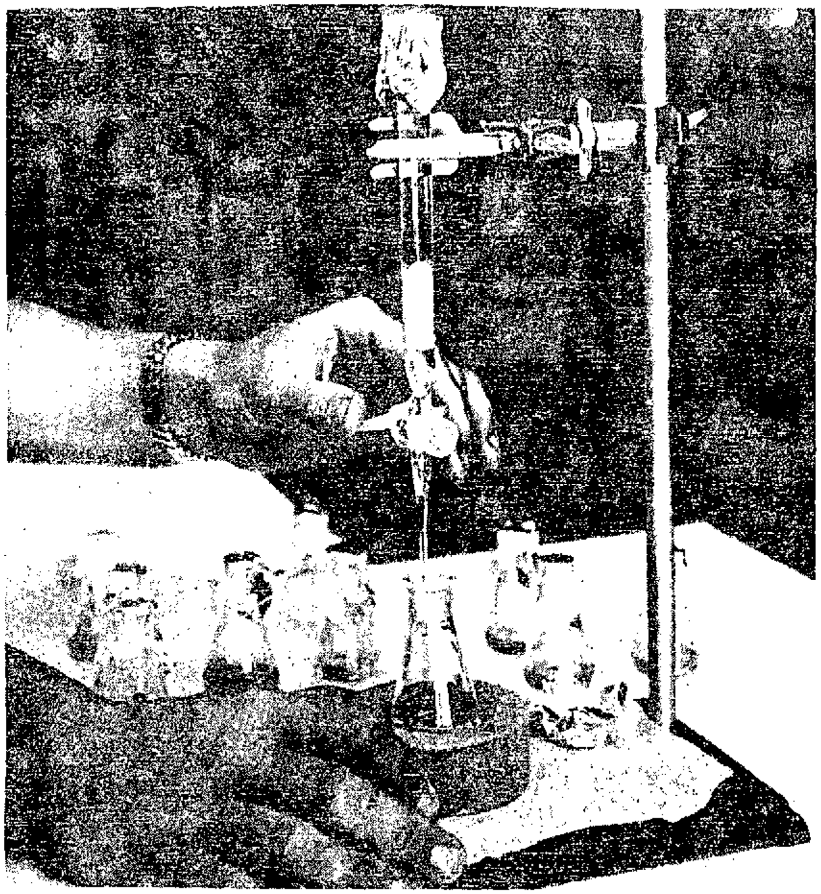
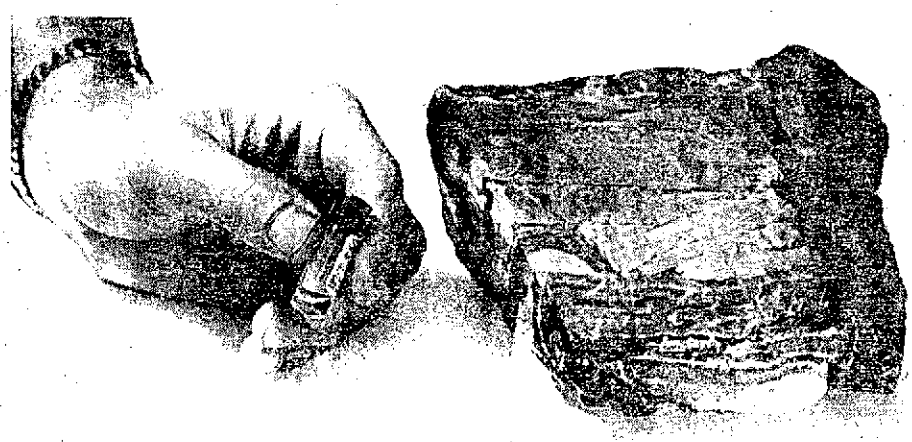


Chromatography experiment

Agreeing provisionally that experimental results are reliable, we must examine the correctness of the conclusions. Accordingly, we can recall the debate over the schist from Minnesota with an age of 2.7 billion years. Characteristics of isoprenoid hydrocarbons and tetracyclic steranes (for example, cholestane) as organic material specific to the schists were subjected to doubt /72 owing to the possibility of migration by this material into the schist from another younger source. Photosynthetic organisms prefer carbon-12 to carbon-13, and the degree of this preference depends on the biological source of the given carbon. Reference was made to differences in the $C^{13}/C^{12}$ ratio between kerogen (insoluble organic matter) and soluble organic compounds isolated from Minnesota schist. In other schists the similarity between $C^{13}/C^{12}$ ratios in kerogen and soluble compounds can indicate a common origin. It was suggested that the insoluble kerogen fraction did not percolate into the rock like kerogen, therefore one must expect in the soluble organic matter the same ratio if it had derived from the same source. But since not all researchers hold the same view on the exact mechanism of kerogen formation, this criterion cannot be held to be beyond debate.

Other arguments in favor of later migration are based on thermal data of Minnesota schist. The formation to which it belongs was subjected, as is assumed, to heating up to 400° C; at these temperatures hydrocarbons would decompose in relatively short order. But the exact temperature and the duration of heating again are suppositional and the question of where the hydrocarbons came from remains open. The case of Minnesota schist shows how many difficulties and cloudy points in attempts to interpret experimental results.

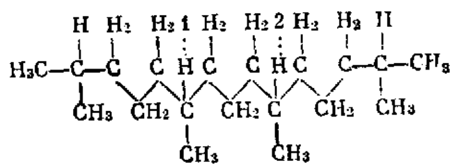
A more fundamental and weighty problem undermining the very foundations of geochemical methods is the question as to whether isoprenoid hydrocarbons were formed abiologically. It is assumed (though this has not yet been shown) that pristane and phytane were found in hydrocarbons prepared by the Fischer-Tropsch method, by which a mixture of hydrocarbons is prepared from carbon monoxide /73 and hydrogen in the presence of a catalyst. It was suggested that



Extract of pedrocarbon isolated from a meteorite isoprenoid hydrocarbons can be produced in the hydrogenization of graphite, though this process still needs to be proven in a laboratory. Though the possibility of the nonbiological origin of isoprenoid hydrocarbons cannot be denied, no has yet proven any one such process experimentallly. At the present time this problem remains unresolved.

In spite of exact analytic methods with which today's organic geochemist works, the true chemistry of pristane and phytane isolated from geological sources remains unknown, and equally as unknown remains its relationship with the stereochemistry of pristane and phytane from biological sources. One characteristic feature of living organisms is that they can synthesize particular molecules in special ways. This feature is expressed in optical activity, that is, the ability of molecules to rotate the plane of the polarization of light.

Let us take the case of pristane:



This molecule has two optical centers 1 and 2; it can exist in two forms:

a) the molecule is symmetrical and therefore is devoid of optical activity; and

b) a mixture of two mirror images of the same asymmetric molecule.

Both these forms were synthesized in the laboratory. Even if they could be separated with gas chromatography in extremely small amounts (of the order of micrograms), then one would also have to solve the problem of the origin of pristane and phytane in geological sources. One cannot anticipate that these molecules in the form examined were synthesized in an abiogenic process. Moreover, the isotope ratio $C^{13}/C^{12}$ was investigated for all hydrocarbon fractions in general, but no one has traced the distribution of these isotopes within the bounds of the same compound. One must be able to find at precisely which carbon atom these isotopes prefer to be attached in a molecule isolated from a biological source and check to see whether this rule is observed in nonbiological cases. A drawback of both methods is the fact that it is very difficult to make these measurements, but with advances in scientific technology they will become more accessible. Then we will resolve the controversy over the biological or nonbiological origin of these hydrocarbons.

As already remarked, organic compounds have been found in rocks fixed at an age of 3 billion years. Proof is mounting that many compounds of a biological character formed in the earth's primordial atmosphere before the appearance of life under the influence of various forms of energy. Experiments determining the effect of ultraviolet radiation, heat, radioactivity, or electrical /74 discharges on various gas systems, for example, on a model of the primordial atmosphere ($CH_4$, $H_2O$, $NH_3$, and $H_2$) led to the production of a wide range of biological vital molecules -- amino acids, fatty acids, pentoses, hexoses, polyamino acids, nucleosides, nucleotides, and polynucleotides. These and other synthetic processes have raised the thought that hydrocarbons isolated from some deposits may be of abiogenic origin. The question of whether to regard these processes as a source of organic materials in alien planetary bodies is vital.

This hypothesis can find further confirmation if we examine the origin of the stars. During the course of nuclear combustion a young star comprising mainly hydrogen and helium passes successively through a number of stages of nuclear synthesis. For example, hydrogen yields helium, helium nuclei yield carbon, helium and carbon yield nitrogen, and so on. As a result, a body is produced consisting of elements or a combination of elements in which H, C, O, and N represent a large proportion. Certain energy processes can in a suitable environment lead to the formation of numerous synthetic organic products, which may become precursors of life processes. And on the surface of the moon, it is possible that conditions exist promoting their preservation in their initial form. These considerations represent a strong argument in favor of the hypothesis that organic compounds similar to materials from carbonaceous chondrites, but free of contaminants, can be found in lunar rock samples.

Of course, conditions on the moon are not favorable to the kind of life that we have now on earth. We cannot detect there a solvent system for the mixing of organic compounds, and this process is essential for the emergence of life. The high density of irradiation, temperature extremes, and high vacuum are also evidently incompatible with life of the earth type. However, there an isothermal layer with moderate temperatures may exist, protected against radiation but admitting enough light in the region essential for photosynthesis. If these conditions are combined with the positive pressure produced by volcanic gases and with a layer of permafrost or other layer of water, then biological activity may also be assumed on the moon. It is also possible that at some time conditions on the moon were more favorable than today and life existed there. Present-day low temperatures and high vacuum are suitable conditions for living organisms to be preserved relatively untouched. We must also consider that the criteria of viability or inviability in space can differ from those on earth. Organized systems using material and energy for growth and reproduction, for their own preservation, and to sustain the integrity of internal systems can exist minimum requirements.

Thus, it is not precluded that the moon will prove to be a fruitful realm for efforts to find biological or prebiological molecules. Knowing the number, distribution, and fine structure of organic compounds, we will obtain information that will aid us in understanding the origin and history of the moon, its rela- /75
tionship to the earth, and to the rest of space. This knowledge is most vital to determine whether life exists on the moon, whether it existed there at some time, and whether it can develop there in the future. The molecular technique provides a much broader approach to the origin of life and does not depend on whether life exists there along with its related processes. When moon samples are analyzed, methods of detection, isolation, and elucidation of organic compound structure developed for investigations of Precambrian beds can be utilized.

In the future, the same methods will probably also be used in analyzing samples sent from other celestial bodies where conditions may prove more favorable to life than on the moon. It may be that some forms of life will be found on Mars, where temperatures are more moderate, and the atmosphere -- though rarefied -- contains water and carbon dioxide. And this will help to determine what attributes of life are essential to living matter in general. Whatever is the analytical information obtained through geochemical study of extra-terrestrial samples, efforts to find the molecular matrix of possible biological and prebiological origin can assist us in finding an answer to several fundamental problems dealing with the origin of life and its relationship to the universe.

# DISTRIBUTION OF LIFE AND THE ROLE OF INTELLIGENCE IN THE UNIVERSE

/76

F. A. Tsitsin

Life outside the earth, life in the universe has only recently entered science as a subject. Several years ago to speak about it in the scientific aspect was "not done," but today this is a fast-developing (though not yet fully formed and even not given a widely accepted name) field of science along the frontier linking astronomy, biology, sociology, and philosophy. In particular, extending from astronomy into this "juncture" of sciences are fields of astronomy that themselves are very broad: astrophysics and cosmogony, planetary and stellar astronomy, celestial mechanics, astrometry, and even cosmology. This is nearly all of astronomy. The other fields of science referred to above are quite extensively represented in this "juncture", as well. Cosmobiology (including the science of astrobiology, understood in a narrower sense) is a field of science with its own specific, exceptionally broad problems, its own methods -- theoretical and observational, and its own difficulties and prospects. These prospects are boundless and sweeping even in the event that the most modest and pessimistic level of anticipations and predictions is realized.

To evaluate the possibility of the origin of life on a planet and -- further -- the distribution of life in the stellar system, of decisive importance is the kind of ideas one has on the process of planetary formation. Obviously, concepts of the Jeansian type of cosmogony automatically leads to the idea of the extreme rarity of life, regardless of the probability of the origin of life on a planet in favorable conditions.

At the present time the concept of the compatibility of processes of stellar and planetary formation dominates in cosmogony. It leads to the conclusion that there are numerous planetary systems and even nearly the obligatory presence of a planetary system at nearly every star. Within the limits of this concept, to evaluate the distribution of life we already need to examine factors whose analysis in practice cannot be reflected qualitatively in results in Jeansian cosmogony. Namely, the fundamental correlations and sequences in planetary formation are very vital, strongly predetermining the answer to the question of the distribution of planets that are favorable for the origin and development of life.

According to one of the competing concepts of planetary cosmogony (Kuiper and others), all planets were formed virtually with identical initial chemical composition, with an enormous content of light elements (hydrogen and helium). Then the latter dissociated, and volatilized from the planet, to the greater extent, the lower their initial mass. Here it is assumed that the inner planets, even though having initial weights tens of times greater than present-day weights lost virtually all their light elements, while the outer planets from the very outset being more massive did not lose all their hydrogen and helium -- even today these elements represent a large fraction of their mass. This concept leads to a heavy limitation on the upper limit of the masses of planets suitable for life, since the existence of life is possible on planets only of the earth type -- this is not the only possible assumption and moreover is not a limiting assumption, but for greater definiteness we will not go beyond it. /77

Much more promising, evidently, is an alternative concept (L. E. Turevich, A. I. Lebedinskiy et al.), according to which inner planets from their very origin had a low content of light elements, for they were formed in the "hot" zone close to the sun out of "naked" dust particles, while the outer planets were formed of particles containing frozen gases. The weak link in this concept is the fact that the freezing of hydrogen on dust under low pressure conditions requires a temperature close to absolute zero, which evidently was not achieved in the proto-planetary cloud (incidentally, the dust disk from which the planets had to be formed, as shown by calculations, was so thin compared with the sun's diameter that it could be "heated" by the sun "from the top" and "from the bottom" -- this would render even more difficult the freezing of hydrogen on dust). As for the helium, as we know it cannot freeze at low pressure however low the temperature.

Thus, even this concept evidently does not satisfactorily account for the disproportion in the distribution between outer and inner planets of the two unevenly distributed elements -- hydrogen and helium. We note that with respect to the lighter elements and compounds, the effect of gases freezing on dust could have occurred.

It appears, however, that the following situation is possible, that does not evidently have the disadvantages of the above-two concepts of planetary formation in explaining the division of planets into two groups. Suppose gas in the protoplanetary gas-dust cloud was not not able to freeze anywhere onto dust and was distributed at a density proportional to the density of dust, or even with a concentration greater than at the dust with increasing proximity to the sun, that is, with relative aggregation in the regions of the future inner planets. If it concentrated in the regions of the future outer planets, our final result would only be intensified.

Let us examine two imaginary protoplanets, the "inner" and the "outer". Suppose that they began to be formed from dust at the same time. Suppose, further, that their growth rate was also the same. Did identical planets then form from them? It turns out that the answer is no. Actually, the temperature in the zone of the inner protoplanet must be higher than the temperature in the zone of the outer. Therefore, under otherwise equal conditions the critical mass at which the planet becomes able to confine gas must be lower in the outer zone than in the inner. In other words, the outer protoplanet having a mass equal to the inner begins to capture gas earlier than the inner. From the time gas begins to be captured, the effective radius of the protoplanet rises sharply. This leads to a speedup in the capture of "dust" as well. The density of gas in the region of /78 formations occurring in this outer planet decreases owing to its concentration in the planet being formed. This must lead to a disturbance in the initially assumed equilibrium of the rotating gas cloud and to the suction of gas from the inner zone to the outer. As a result it may have occurred that at the moment when the inner planet growing exclusively owing to dust aggregation reached the mass critical for its distance from the sun (that is, began to be able to capture gas), there was nearly no more gas for it to capture. All the gas could have already been sucked from the cloud by the "faster competitors" from the outer zone.... Therefore the further growth of the inner planet would continue only by adding on dust (which could not be sucked into the outer zone and could not be entrained by gas streaming there).

As a result we arrive at the situation of the formation of earth and Jupiter types of planets (in the inner and in the outer zones) in complete agreement with facts. Let us emphasize that in this concept the decisive point is allowing for the factor of competitive gas capture, where no longer do we need the assump- of the extremely low temperature in the outer zone (which is inadequate even in the original version of the Gurevich-Lebedinskiy hypothesis) to account for the origin of planets of the two types; all we need is a simple decrease in temperature in the cloud with distance from the sun.

The reduction in planetary masses and in the hydrogen content beyond Jupiter also is naturally explained from the standpoint of this hypothesis. The dust cloud could not be strictly identical everywhere in the protoplanetary cloud, and evidently decreased toward its extremes (inner and outer). With respect to a pair of the "Jupiter-Earth" type, this factor must have led to a buildup in the effect we are considering. But with respect to the "Jupiter-Pluto" pair, a decrease in dust density in the protoplanetary cloud from the zone of the first member of the pair to the second must in some way have weakened this effect. Suppose assuming the simultaneity of the onset of growth, the growth rate of "proto-Pluto" was -- due to the lower density of the dust disk -- smaller than for "proto-Jupiter". In spite of the lower temperature in the "Pluto" zone, "Jupiter" still could have reached its critical mass earlier than "Pluto", and so on. This should have led to "robbing" by "Jupiter" even of its outer neighbors through capture of gas from their zone. This evidently also accounts for the lower content of light elements in "Pluto" compared with "Jupiter". However, as we noted, it was more difficult to "rob" the outer neighbors than the inner planets existing in an exceptionally disadvantageous situation in this regard. The latter had both the temperature and the "density" factors operating in the same direction, and not in opposite directions, as should have occurred with respect to the "trans-Jupiter" planets.

From the standpoint of these concepts, the inner planets, whatever was their mass and in the vicinities of whatever star they were formed, must be "earthlike" in chemical composition. This circumstance is very essential in evaluating the probability that the mass of a planet is favorable for the possibility of /79
life originating and existing on it.

Whatever was the mechanism of the formation of our solar system, in all probability it was typical. This enables us with a high degree of certainty to state that its general structural features must be typical of nearly any planetary system. Evidently, during the formation of any planetary system the process of averaging of chaotic movements during the course of the merging of some relatively small elements into larger bodies is of essential importance. However, besides this qualitative statement, we need to establish a definite quantitative characteristic that we can assume to be general for different planetary systems. Namely, an examination of the dependence of planetary mass on the eccentricity of planetary orbit with the example of the planets in our solar system carried out for earthlike planets will enable us to formulate a hypothesis that appears extremely plausible: if the mass of planet is sufficient to restrain an atmosphere, the eccentricity of this planet's orbit must be small.

With the foregoing in mind, we can attempt to revise our answer to the question of how frequent are foci of life in the universe.

The view is held that only one of $10^5 - 10^6$ stars can there be a sun with an inhabited world. This estimate of the probability of finding life in the vicinity of any randomly selected star is given in a book by Academicians A. I. Oparin and V. G. Fesenkov, Zhizn' vo Vselennoy /Life in the Universe/ and has gained wide acceptance. The authors estimate the probability of various factors regarded as essential for life to exist on a planet. Assuming further that all these factors are independent, they get a final estimate by multiplying their probabilities. Let us consider the corresponding factors and attempt to revise their quantitative estimates. Let us also take account of certain factors that are not considered in the book Zhizn' vo Vselennoy.

1. In the book it is stated that to keep the temperature in the favorable limit, the orbit of a planet must be extremely close to circular (the factor of small eccentricity). The probability of a small enough eccentricity is evaluated as 0.5. But, as noted above, the "eccentricity" factor is associated with the factor of sufficient (to confine an atmosphere) mass. Given a suitable planetary mass, the eccentricity of the planet's orbit must be sufficiently small. However, the authors of the book do not allow for this dependence, which leads to understating the unknown probability. Allowing for the observed and obviously nonrandom relationship between planetary mass and the eccentricity of a planet's orbit and eliminating the assumption that these two parameters are independent gives us not 0.5, but virtually 1.0 for the probability of a favorable eccentricity.

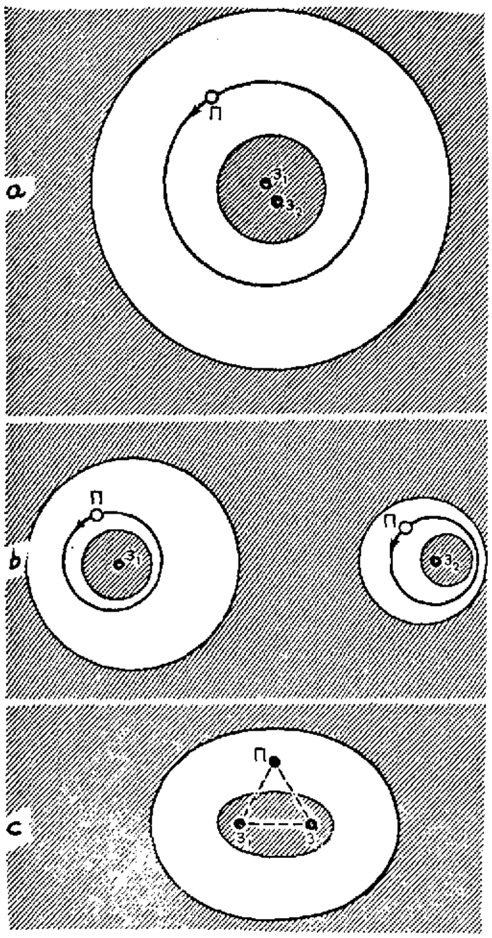
2. It is further stated that life is impossible in systems of multiple stars. Planetary orbits in this case would inevidently be marked by extreme complexity, leading to abrupt temperature fluctuations on a planet. But since according to some data up to 80 percent of all stars are part of multiple systems, the probability of life within the vicinity of any randomly selected star must be reduced because of this factor by another five times.

However, the categorical assertion that sufficiently simple planetary orbits in multiple systems are not possible is not quite exact. Such orbits (entire classes of them), as shown in celestial mechanics, do exist. They can quite strongly include sufficiently stable orbits. Thus, in a double system, near-circular stable orbits can exist around a sufficiently close pair as a single center of gravity; but in the case of a fairly broad pair these orbits can exist in the vicinities of each of the components. A planet continuously in a favorable temperature zone can also lie in the so called triangular point of libration. /80

In this case the entire system rotates as a gently "pulsating" or rigid triangle about a common center of gravity.

Let us note that systems of higher multiplicity as a rule have a structure of the elongated triangle type, so that the motion of planets about a close pair in the ternary system can only be weakly disturbed by the effect of the third component,

and so on. Mathematically, here a curious circumstance arises: if even one planet with a biosphere is in a system of an n-multiple star, then this will provide for the existence of life in the vicinity near n stars. Therefore estimates of the probability of detecting life in a multiple system must enter in the final calculation with an n-fold increased weight. Allowing for these circumstances, the probability of the absence of a planet favorable for the origin of life in a multiple system must be much smaller than 1. Estimating it as 0.5-0.3, we get the result that life can exist in the vicinity of 50-70 stars out of each 100 that are in multiple systems. Therefore, a cofactor not of 0.2, but 0.6-0.8 must enter into the final estimate of the probability /81
that depends on the effect of star multiplicity.




Arrangement of planetary orbits within zones favorable to life in systems of multiple stars. The hachured regions indicate the zone of temperature unfavorable for life ( П = planet, З = stars)

3. The probability that a star is not too young or does not have luminosity that changes too rapidly (massive stars) or a variable luminosity, is evaluated as 0.1. However, available statistical data on the number of such stars show that variable, massive, and similar objects more probably constitute not 0.9, but less than 0.1 of the population of our galaxy. Further, the age of the sun and of solar system is of the order of 5 billion years. There are data indicating that life existed on earth already 3 billion years ago. Thus, in our case (with which we can only rely in quantitative estimates), 2 billion years if not less proves to be sufficient for the origin of life

in the vicinity of a star. Therefore even if the rate of stellar formation in our galaxy were unchanged since the beginning of its forming (approximately 10 billion years ago), then not 0.1, but 0.8 of all stars would be "old enough" in order for life to be able to appear in their vicinity. But it is doubtless true that owing to the inevitable gradual exhaustion of prestellar matter the process of stellar formation in our galaxy weakened with time. Therefore stars that are too young (formed in the last 2 billion years) must represent no longer 20 percent, but much smaller proportion of stars in our galaxy.

And so, the probability of a value of this factor favorable for the existence of life is not 0.1, but virtually close to 1.

4. The authors of the book introduce a factor equal to 0.1, accounting for the probability of life existing on a randomly selected planet about a randomly chosen star. However it is not required to introduce this factor. Actually, in the model of a stellar system where there are 10 planets around each star, one of which is inhabited, the unknown probability of detecting life in the vicinity of a randomly selected star is 1; but introducing the factor proposed by the authors of the book would yield a value of 0.1 in conflict with our condition.

5. Finally, the probability that the mass of a planet is not too small (sufficient to hold an atmosphere) and not too large (in order for hydrogen and helium comprising, according to the concepts of the book's authors, most of the initial mass of a planet, to be able to dissipate) is estimated as 0.01. Incidentally, a significant force of gravity at the surface of a massive planet could of itself proved to be a factor not favoring the origin and development of living organisms. We note, however, that for earth type planets considerable mass need not have impeded the origin and development of life. On the one hand, the force of gravity at the surface of a planet increases much more slowly than its mass: $g \sim (M/\bar{\rho})^{1/3}$ (g is acceleration due to gravity at the surface, M is mass, $\bar{\rho}$ is the mean density of the planet), and on the other hand -- and this is vital -- life was initiated and achieved high development in a "medium without gravity" -- in water, nearly unquestionably. Let us point out, incidentally, that in a very massive planet earthlike satellites can form having a mass sufficient to restrain their atmospheres. As far as chemical composition is concerned, in accordance with the foregoing according to the very mechanism of planetary /82
formation the chemical composition of inner planets evidently must be earthlike. Thus, for masses of earthlike planets suitable for life virtually does not exist.

The limitation as to small masses also is obviously minor: actually, the earth and Venus have a more than tenfold mass reserve compared with the mass that is the minimum required to hold an atmosphere. Thus, even examining the problem as a function of the distribution of the momentum of multiple systems (on the assumption of a continuous transition from such systems into planetary systems) leads to the conclusion that only a negligibly small fraction of planetary systems acquire momentum insufficient to form inner planets capable of holding atmospheres. Hence the probability of a favorable planetary mass obviously differs little from 1. The value of 0.01 appears to be severely understated and unjustified.

Instead of the value of $10^{-5}$ for the probability of detecting life in the vicinity of a randomly selected star and the value of $10^{-6}$ taken "for insurance", we get the number 0.5-0.8 with a more vigorous scrutiny of the same factors.

6. We however note that introducing an "insurance factor" of 0.1 into the unknown probability is fully justified upon further examination. Namely, E. A. Dibay showed that since stars earlier formed in our galaxy ("first generation") and evidently comprising about 0.9 of its population must contain very little of the heavy elements, then earth type planets consisting mainly of heavy elements could probably not have formed about them. This limitation means that stars that have planets suitable for the development of life must be young enough to be formed from a medium enriched in heavy chemical elements ejected from deep within certain exploding stars of the first generation. This condition then introduces a cofactor of 0.1 into the unknown probability.

7. We must take account of the presence of dwarf stars comprising possibly about 0.9 of the stellar population as a factor that may prove to be substantial. Owing to the stars we must introduce a "indeterminacy factor" of 0.1-1.0 into the final estimate, since it is unknown whether biospheres exist in the neighborhood of these stars.

With all these seven factors accounted for (multiplying their probabilities we have presented and slightly expanding -- as a precaution -- the resulting range of values), we find an estimate of the order of 0.1-0.001 as the sought-for probability.

Of course, if a star is not selected randomly (if we know, for example, that it is a single, sunlike, and not variable star), then the probability of the existence of a life-favorable planet about it can be evaluated with greater definiteness and certainty. Concretely, within the bounds of our argument and estimates, it is close to 1. If life emerged under favorable conditions near in all cases, then the probability of life existing about this star will be close to 1.

These are the main results of examining the question of the distribution of life in the universe (and more accurately, in a stellar system of the type of our galaxy). In principle these considerations and estimates can be extended to the case of stellar systems of other types. However, in the case of elliptical galaxies there are a number of singularities deserving special notice. Namely, in elliptical galaxies matter ejected by first-generation massive evolved stars rapidly "falls" into the central region of the system and here forms second-generation stars. Third-generation stars are formed even faster, and so on. At the same time, in galaxies with a considerable specific rotational moment (spiral galaxies), the change of generations proceeds not as rapidly owing to the presence of a field of centrifugal forces impeding the rapid attainment of the critical density by the matter ejected from stars of the preceding generation. /83

As a result, in the elliptical galaxies chemical evolution occurs faster than in spiral galaxies, and conditions for the origin of earthlike planets in stars of elliptical systems are provided in general faster than in spiral galaxies. Therefore we can assume that in elliptical galaxies life emerges, under otherwise equal conditions, faster than in spiral. Therefore, we can anticipate the presence of more numerous and especially older and more developed foci of life in elliptical galaxies when compared with spiral galaxies of the same age.

Note, however, that in these considerations we had not allowed for the possible influence on life development on the planets of a stellar system of cosmogonic processes on a galactic scale. We have in mind, for example, the activity of galactic cores, which at a certain level and nature can be a factor both promoting the development of life (enriching the factors of pre-biological evolution and intensifying the mutational process), as well as preventing the very emergence of life ("sterilization" of a planet with extreme doses of hard radiation, for instance).

Further, from the above it follows that conditions for the formation of earthlike planets in an elliptical galaxy are produced, in contrast to spiral galaxies, not in the elongated region in the neighborhood of the plane of symmetry, but in the relatively small central zone of the system. Stellar density here can be large enough in order that the close stellar approaches perturbing the motion of planets about the corresponding stars are not negligibly infrequent. This can disturb conditions essential for the inception and development of life on planets in any regular fashion, by reducing the probability of life existing in the core zone, that is, in the elliptical galaxy in general. Interestingly enough, this consideration was advanced as applied to a spherical cluster even by W. Herschel more than one and half centries ago.

To estimate the distribution of life, it is important to determine the probability of its emergence on a planet. This question is still unclear. The thought that in favorable conditions life emerges sooner or later "by necessity" appears plausible.

Strictly speaking, any reasonable mechanism for the emergence of life on a planet has a probabilistic side, a probabilistic aspect. Actually, depending on specific avenues of the formation of further evolution of a planet, conditions on it can favor the emergence and development of life to differing degrees. We can introduce as a quantitative characteristic of the favorability of conditions for the emergence of life on a planet the probability of life appearing on it, let us say, during the first two billion years after its formation. Clearly, this probability can differ for different planets. This may depend, for example, on the nature of the orbit. If the orbit has a considerable eccentricity, then at its aphelion, when there is an appreciable decrease in the temperature zone the planet, the process of prebiological evolution of matter can be slowed down compared with what occurs on a similar planet with a nearly circular orbit. /84

The probabilistic quantitative characteristic of the favorability of the entire sum of factors for the emergence of life on a planet is convenient also because it enables us to estimate the resulting influence on the emergence of life of the full, exceptionally rich, complex, and heterogeneous array of conditions of prebiological evolution on a planet.

The probabilistic characteristic of the emergence of life on a planet is meaningful also in that the process itself can by its nature be realized and can lay out its pathway through a sequence of independent, chance "events" on the planet. These may include, for example, the formation and sufficiently long existence in some part of the planet of extensive bodies of water shallow and well-heated by the sun, where the conditions of prebiological evolution evidently are most favorable. On a planetary scale, the formation and disappearance of such aquatoria represent details of geological evolution, to a large extent fortuitous, and dependent on an extra ten or more meters in the height of the shoal marking off the shallow basin from the ocean, and so on.

We can illustrate the role of the factor of chance in the process of life appearing on a planet in a very graphic form with the following example. There is a point of view according to which the course of prebiological evolution on earth depended heavily on the enrichment of its chemical composition with

abiogenic organic substances that the earth obtained upon collision with comets. Clearly, these collisions are random events in each individual case. But over a sufficiently long interval of time they acquire the features of a process occurring by necessity. Here is an arbitrary model of such a process enabling us to discover with greatest clarity the dialectics of chance and necessity during the emergence of life on a planet. Imagine to yourself that for the successful occurrence of the emergence of life on a planet it is necessary and sufficient to have a quantity of abiogenic organic matter supplied by a single comet. In this model the process of the collision with the comet can be examined, for sake of simplicity, as pressure on a release trigger leading to a "shot" -- the appearance of life on the planet. Even abstracting from any other fortuities favoring or counteracting the emergence of life, in this scheme the process of life's appearance will prove to be a stochastic process, /85
random, and dependent on whether a specific single chance event (the collision with the comet or, for example, completely arbitrarily -- the emergence of the "first living molecule") occurred or did not occur.

The view is held that this concept of the "chance" emergence of life supposedly inevitably leads to the idea of its extreme rarity. Accordingly, it has been asserted (by I. S. Shklovskiy) that the detection, for example, of life on Mars would be a decisive refutation of the concept of the chance origin of life independently on different planets and in different stars. However, this view is based on miscomprehension. The probability of the chance event necessary for the emergence of life during a specific interval of time can be characterized by some quite definite number. Suppose this probability reaches, for example, the value of 0.5 in $10^8$ years. Then the probability that there would not be life $10^9$ years after the formation on the planet of conditions permitting the emergence of life proves to be less than 0.001. Thus, this chance must be realized virtually by necessity during a cosmogonically relatively short interval. Only in the case when the probability of the random events necessary for the emergence of life becomes close to 0.5 during a time considerably exceeding the life of an average star, only in this case would the distribution of life with the given "chance" mechanism of its emergence be extremely small in a stellar system.

Thus, the emergence of life as a result of the action of a chance process, given its complete independence on different planets, does not at all mean that life is an extremely rare phenomenon in our galaxy. Proof of the existence of life on Mars within the framework of the concept of an independent "chance" emergence of life on different celestial bodies, combined with the fact that life exists on earth would quite readily enable us to conclude that the "time constant" of this random process (the characteristic time for the emergence of life) is cosmogonically small and life must be widely distributed in our galaxy. Note that within the framework of the concept of the panspermia type (the transportation of germs of life from one planet to another), the detection of life on Mars would not mean that this is an ordinary event in a stellar system. In contrast to the usual version of the panspermia hypothesis, in this representation no related, genetic ties exist between the organisms of the different worlds. Therefore all forms of similarity of living organisms in different worlds must be accounted for exclusively by the phenomenon of biological convergence, that is, by the evolutionary drawing closer of morphological features of organisms of different kinds living in similar conditions. /86

Though life evidently is a very widespread phenomenon in the stellar universe around us, this does not yet mean that rational creatures can also be encountered in every corner of our galaxy. We must emphasize that we do not know how typical is the process leading on earth to the emergence of the species Homo sapiens; we do not know how regular and to what degree random and "fortunate" was the combination of conditions and their changes leading on earth, after several billions of years of "unconscious existence," to the appearance of rational creatures.

Resolving the problem of the distribution of rational life in the universe must be pursued along the avenue of investigating the very nature of reason, and on this basis -- studying the correlations in the emergence and development of rational forms of life, as well as by direct efforts to find the presence of rational forces in the world around us. We note that the prolonged failure to detect traces of rational life in space would not mean that it is absent or it is extremely of small distribution. We are too young and inexperienced to be confident that we have properly represented to ourselves the trends and directions of "mature" mankind. We are measuring by our own yardstick and are inevitably ascribing to our hypothetical rational "neighbors" our own cast of thought, our present efforts at broad contacts, to an ever deeper penetration into space. We /87
are extrapolating ourselves based on our contemporary, still very incomplete and inadequate knowledge about even ourselves and we are assuming that in so doing we are acquiring a notion of typical mankind the "cosmic" phase of its existence. We are prone to take as typical the conditions in which life exists on earth, and this perhaps is not all so.

Incidentally, we probably have not detected appearances of activity by other rational creatures in the universe not because highly developed civilizations have begun to adhere to the doctrines of their unique "cosmic isolationism". It is possible that the point is that rational creatures in space are still very infrequent or else we have simply not learned how to distinguish traces of reason, though perhaps we have long since been encountering them. Whatever the case, efforts to find traces and manifestations of "rational life" in the world around us are altogether essential, in particular on our earth. This is a problem of looking for a "miracle" phenomenon, which could not be explained without the assumption of the activity of rational creatures unknown to us. This question is being widely discussed but unfortunately not always at a high scientific level. It is all the more necessary to examine seriously scientific arguments in favor of the thesis that proof exists for the presence of traces of another kind of mind on earth, in the solar system, in the world of the stars, and even of the galaxies.

The absence of "miracles" (if they actually exist, and do not remain simply undetected) can be accounted for by the fact that the conditions in which a typical civilization emerged and developed differ so appreciably from ours in the direction that sharply impedes the cosmic manifestation of life and all the more so emergence into space. It is not precluded that we have been greatly fortunate in the combination of conditions favoring our understanding of space and -- further -- of "mastering" it. Imagine to yourself, for example, a planet whose surface is entirely covered with water, however advanced would be the development of its inhabitants, however far they would deserve the /88 title of sapiens, to make themselves evident on a cosmic scale would be incomparably more difficult for them than for us.

But suppose that there is dry land on the planet. And what if its sky, like the sky on Venus, is always covered with clouds? Could the inhabitants of this planet learn much about space? How greatly would the development of their civilization be retarded and along what avenue would it have proceeded? In any case, it is clear that the very task of interplanetary flight could not have been formulated before the starry heaven itself, which the earth's inhabitants had contemplated already billions of years ago, had been discovered....

Is there any single exclusive general avenue along which a civilization develops, along which any society of rational creatures eventually emerges, or are they many such avenues? Can we anticipate a distinctive convergence, a similarity of the "content" of civilizations (and possibly, as a function of this -- a similarity of external bilogical features of rational creatures), or is their diversity not limited in anyway? It appears more probable that convergent evolution of indepdent civilizations and their bearers exists -- in any case, for those civilizations that ultimately enter into space. In this "environment" the conditions of the existence and the natural forces opposing "man" proved to be practically the same, independently of whether this occurred around the sun or in the vicinity of some other star in a remote galaxy.

K. E. Tsiolkovskiy foresaw the possibility of the biological evolution of man in space in the direction of "ethereal creatures" described by him, freely living in the vacuum of space and obtaining energy by the same principle as do plants. One may smile at such a picture; but who knows whether this smile is similar to the smiles that the very idea of interplanetary trips caused half a century ago.... We must also make allowance for the fact that "man" as a biological species can gain power over his own evolution and direct it along a desired avenue. Will the desires and ideals of inhabitants of different worlds coincide in this?....

It has already been a number of decades ago since one insightful Englishman foresaw the time when man could "turn stars on and off with a switch." At that time this was a bare extrapolation of the growing power of man. But today concrete ways in which this promise can be achieved are being probed and discussed.... The time possibly is not far off when energy comparable and exceeding stellar energy in power will be in the hands of man. And then mankind will prove to be a decisive force determining the evolution of our entire stellar system -- our galaxy. As a result, the entire Metagalaxy may prove to be under the control and direction of rational creatures of different galaxies, and rational life will prove to be already a cosmological factor governing the channels for matter's development in all the now visible expanses of the universe.... /89

But now we find ourselves in an "old" difficulty -- the "heat death" problem. The conclusion appears inevitable that if the world around us converts into a thermodynamically equilibrium state, then for man history must be "wound up" and called quits.... Is this so?

In recent years efforts to find the "ascending branch" in the turnover of energy predicted by Engels have become more vigorous, even though the subject, in contrast to the subject "life in the universe" has likely not yet entered the realm of those with which a scientist can be personally involved.... In any case, it is hard to doubt that the dead end of heat death is an illusion, that the turnover of energy and, therefore, in principal avenues of controlling it objectively exist (however far this idea is discredited by naive and incompetent attacks on the second law of thermodynamics when its "obvious contradictions" with experience are examined in the very fact that energy concentrates in living nature, in the course of stellar formation, and so on). We note that systems and devices by means of which energy turnover would be brought into a closed circle would be nothing other than a "second-order perpetual motor" in the exact sense of this term.

The concept of the validity everywhere in the universe of the second law of thermodynamics in the statement, "A second-order perpetual motor is impossible," is supported by experiment for a wide range of phenomena, and is extrapolated for remaining systems and scales of phenomena (often implicitly, as the conservation of parity is extrapolated for the realm of weak interactions). Attempts at proving it have not led in the general case to comprehensive results. Moreover, with the origin of the molecular-kinetic concept of thermodynamics, the prospect has appeared not only of substantiating the second law of thermodynamics, but also -- dialectically -- the idea of the possible limitations on its validity even as a postulate on the impossibility of a second-order perpetual motor. This is the idea of the "Maxwellian demon" and the hypothesis that the concentration of fluctuations is possible (in systems with microvalve devices). The view is widespread that the paradox of the Maxwellian demon will finally be eliminated with the aid of the concepts of information theory (Szillard, Brilluoin, Wiener, and others). However this idea is in error, since the problem remains open for the most interesting case -- the "demon" oriented with the aid of short-range forces (essentially, identical to the molecular valve).

True, the view is held that the impossibility of violating the second law of thermodynamics with molecular valve type devices has supposedly been already demonstrated by Smolukhovskiy and is explained by the fact that any such device in a real universe possesses intrinsic fluctuations. But analysis of the arguments of Smolukhovskiy revealed several gaps and inexactitudes. The main error was to use postulates of statistical mechanics as a prerequisite. This led to a vicious circle, for historically the foundations of statistical mechanics were actually constructed in order not to contradict thermodynamics (that is, also the second law). With allowance for this and other errors, it is found that the question of the possibility of violating the second law by fluctuations in dynamically essentially nonlinear thermodynamic systems (of a type containing a molecular valve) remained open. The main error of Smolukhovskiy's was systematically reproduced by later authors (quite recently, for example, by F. V. Bunkin and R. Feynman). /90

It is therefore not precluded that the inapplicability -- when fluctuations are present -- of the second law of thermodynamics in the statement, "A second-order perpetual motor is impossible," can be possible. This does not contradict the validity of the second law for systems investigated until now within the attainable limits of precision, since among systems studied there are none in which one could expect an increase in an effect up to quantities discernible in practice owing to the accumulation of the effect in time or in space -- in a cascade.

The only possible exception is represented by biological membrane ultrastructures. But it is precisely here that there are a number of effects that have not yet been explained within the framework of known laws of physics -- the mechanisms of "active transport."

These conclusions are of particular interest from the standpoint of the possibility of the forms in which life developed in the universe. If, for example, the control of the turnover of energy can be achieved in biological microstructures (it is interesting that even Helmholtz did not preclude this possibility; and later it was pointed to by Borel, P. P. Lazarev, and others), life would remain essentially more autonomous and with respect to thermodynamic conditions life would be an environment that one would assume would be able to develop even in the equilibrium dark and hot depths of the atmospheres of semiplanet-semistars, and so on. Further, the conclusion that thermodynamic waste in the form of infrared radiation is inevitably present in Dyson spheres (the "Pokrovskiy plate") is groundless. The only forced manifestation of this kind of inhabited world proves to be the opaqueness of its envelope. In the universe there may be a multitude of highly developed civilizations for whom it is thermodynamically advantageous and attainable not to dissipate energy at all. But why then do we not see traces of the "other reason" in the universe?....

A civilization controlling the turnover of energy in a certain sense is infinitely more powerful than a civilization of any of the Kardashev-countable class. It not only can exist in a steady-state manner even in a thermodynamically equilibrium universe around it, but has even the possibility of the unbounded expansion of its areal, by removing from thermodynamic equilibrium an unlimitedly enlarging realm of the universe.

# SPACE AND PALEONTOLOGY



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At the dawn of the space age, in an epoch of a vigorous and not yet organized development of science, many of its fields are undergoing a re-evaluation. Paleontology has not escaped the common lot. At first glance it is difficult to see a connection between a discipline studying remains of life from long-past times extracted from the depths of the earth and sciences of the heavens exploring the abyss of space.

To each seeker of knowledge, let alone paleontologists and geologists, it is given to dream of how to reflect in all fields of knowledge, philosophy, and just the individual's world view the results of paleontological excavations on Mars, Venus, or let us say, on the planet of the star 61 Cygni. Even if the planets prove to be uninhabited, then perhaps the rock strata on their surfaces preserve the remains of life once existing there and now it is gone. We will read its tragic history by compelling the extinct world to bring to light the secret of the catastrophe that swept living matter from the planet. On planets bearing life, but not populated by rational creatures, we will study the ancient fossil soils and perhaps will be able to learn the reason why through did not blossom here.

As for the worlds where there are civilizations on a level with ours or even higher, their inhabitants doubtless have delved into their prehistory and upon contact with us will highlight the pathway of the historical development of life leading to the emergence of the intellect that is aware of nature and itself.

What then must be the life forms not only on planets of remote stars, but also on the neighbors of the earth in the solar system? Will not these forms prove to be so dissimilar to our own, terrestrial forms that even if they were rational, we could never find them and even less understand each other?

By the tradition founded in science in the first half of our century when a serious interest in astrobiology appeared, the reply was negative to all these three questions. Millenia of anthropocentrism have still too profoundly permeated the subconscious aspect of scientific thought for man to be able to grasp the infinity of space and time and to appreciate that by recognizing the unfathomable depths of the material universe, one cannot but admit the existence of countless centers of life.

Astronomers like J. Jeans, asserting that the appearance of a planetary system in the vicinity of a star is a highly infrequent event were echoed by biologists and paleontologists, who believe, as for example, J. Simpson, that the appearance of life on any other planet, let alone rational life is so far beyond the bounds of remote possibility that its probability of happening again is practically zero.

Orthodox Darwinists showed that the pathway of organic evolution is absolutely blind, for it is subject only to the fortuities of all-powerful natural selection, selecting random mutational changes in hereditary mechanisms. Orthogenesis, that is, the directedness of life's development unswervingly tending toward complex, highly organized forms, all the way up to a thinking creature, has long been regarded as idealism. Therefore, it was natural to conclude that evolutionary development is unique and irrepeatable. A second logical conclusion was the recognition of the greatest possible diversity in the structure of life forms. Even in identical conditions one must expect the manifestations of the most dissimilar, absolutely unlike creatures. /92

But if the environment of life on other planets differs from that on earth in given parameters, then in blind, chance evolution rational life, invested in an unpredictable form and chemical composition, could not deliberately have anything in common with terrestrial life. Some researchers poorly versed in biology have insisted on the possibility of the emergence of thinking creatures in the form of fungi or lichens. Such views of organic evolution do not leave any hope for the existence of inhabited planets with thinking creatures and deny the possibility of contact with the alien intellect of the inhabitants of stellar worlds or even planets in our solar system. The uniqueness of life has engendered a sad sense of limitless solitude and, if one is a consistent materialist -- the purposelessness of the existence even of rational life. As always happens when a concept is not fully mature, it merges with religious anthropocentricism that views man as the universe's only creation of divine likeness.

The incredible surge in scientific research in the second half of our century has substantially modified former ideas. A major achievement in science has been the proven view of the tremendous complexity of the universe and the phenomena occurring in it. A complexity of which scientists did not suspect even at the beginning of our century and only the materialist philosophers, and above all, Vladimir Lenin, lucidly foresaw it.

The one-track logic pursued by those who advocate the uniqueness of life and man as its highest thinking form fell apart under the avalanche of new discoveries. The first fundamental blow against the ideas of uniqueness was struck even in the past century by astrophysics that proved indisputably that the universe everywhere, even in its most remote realms barely accessible to our instruments, consists of 92 main chemical elements. Their quantitative ratio showed the predominance of some elements, such as hydrogen, helium, oxygen, silicon, and iron, and the strikingly small role of the others. We have not yet found the reason for this and only suspect that these elements as forms of the existence of matter are universally stable in the most common phase conditions. Evidently, the distribution and the elementary composition of giant clusters of matter in space is not pure accident.

Thus, the 92 elements of the universe restrict the array of possible alternatives in energetics and in the temporal extent of living matter. Actually, life had to be assembled not from 92, but a much smaller number of elements -- no more than ten. Therefore the number of stages ascending to the highly organized life form inevitably must be severely restricted. This circumstance, by limiting the chemical foundations of life, apparently blocks the frequency of its repetition. This perhaps could be if life that we observe on our own planet did not utilize chemically precisely the most common elements in space. The entire turnover of life transformations proceeds within the limits of elements comprising more than 99 percent of matter in the universe. /93

Further successes in astrophysics refuted the uniqueness of the solar system and showed that planets around stars are not so rare, and in the aspect of infinity, their number in the universe must be extremely large. Correlations appeared in the composition of planetary atmospheres and their changes in time. Evidently all primary planetary atmospheres consisted of a thick cover of light gases and were similar to the atmospheres of the large planets of our solar system -- Jupiter, Saturn, Uranus, and Neptune. The escape of hydrogen, methane, and ammonia into space under the effect of radiant pressure and solar heating ultimately, as happened on earth, enabled solar radiation to penetrate into oceanic waters and onto the surface of the planet, producing conditions for photosynthesis and later for the accumulation of free oxygen. At the same time the primaeval methane-ammonia atmosphere saturated with electricity could have produced -- during lightning discharges -- amino acids -- the primary molecules of life. According to other views, after the dawn of the existence of the earth's atmosphere it had a considerable hydrogen cyanide content, also promoting the partial emergence of proto-organic compounds. Further evolution of the planet's atmosphere proceeded under the influence of the development of plant life -- the accumulation of free oxygen along with considerable thinning out of the gaseous cover.

Thus, all the data of geophysics and astrophysics allow us to speak of some single primaeval type of planetary atmosphere in no way blocking the emergence of life.

A revision of data on the age of our planet has considerably increased its former age. There are grounds to maintain that the age of rocks comprising the most ancient continental shields is close to 5-6 billion years. So the discovery in ancient sedimentary rocks of these shields, in particular the South African shield of clear remains of life aged at about 2.5 billion years, was not astounding. There is no doubt that the first appearance of the initial forms of life -- protolife -- took place even earlier.

The enormous duration of the first stages in the development of life on earth lets us appreciate how the astounding complexity of organic structures during evolution necessary for the existence even of the simplest organisms could have occurred. Still, the antiquity of life shows the invincible persistence of the process in time and its just as invincible directedness toward complexity and perfection of biological mechanisms.

Yet another of the most important discoveries in the second half of our century -- cybernetics (along with information theory)-- -- demolished the last strongholds of anthropocentric thought.

Even the first attempts at creating self-regulating and self- /94
perfecting systems made it possible to represent the historical development of the most complex animal forms. Computers brought us closer to comprehending the operation of the brain and the individualized information stored in it, and for the first time, provided a materialist explanation for the instincts and reflexes as information accumulated during historical development and stored in hereditary mechanisms. Without any doubt, the same laws of nervous activity under which the storage of information and its utilization proceed operate in the universe.

Fred Hoyle pointed out that all information required to construct a most complex creature such as man is stored in a single cell with a volume of somewhat more than 15 cubic microns, consisting nearly entirely of a nucleus of DNA, which is the spermatozoid. If the "packing" and storage of this information had attained this perfection, it is difficult to assume the possibility of systems more chemically complete. Evidently, we are dealing with one of the best achievements of evolution that was doubtless utilized in the main stream of life in the universe. We can therefore be certain, concludes Hoyle, that the forms of life on other planets are close to those on earth.

The latest discoveries of the exact sciences and their application to biology lead us to the representation of life as the inevitable state of the development of matter anywhere there are suitable conditions and above all sufficient duration and constancy of these conditions. The great array of planets in the universe presupposes the probability of the abundance of inhabited worlds, and what we know about the mechanisms of regulation and control compel us to believe that the appearance of thought and of rational creatures is also an inevitable consequence of the prolonged development of living matter.

Now let us examine what paleontology tells us, that is, the actual documentation of the journey covered by the historical development of terrestrial life over an interval of half a billion years -- from the most ancient reliable remains to our day.

Like the history of human society based on certain documents, the first fossilized remains capable of being used to interpret the structure of the ancient organisms are those of already highly complex animals or plants entirely adapted to their environment. Without any doubt, this is the tip of the iceberg projecting above the water. The "water" in this case is already not less than two billion years of prehistory during which all the main groups of animals were formed, while the plants probably had already begun to adapt to dry land.

The enormous gaps in geological documentation due to regular discontinuities in the deposition of sediments and the wiping out of earlier deposits greatly limits our possibilities of learning about the first stages in the conquest of land by plants as well as by animals. Nonetheless, the total array of paleontological data gives us an irrefutable general picture of gradual growing complexity and perfection of plant and animal forms during the course of geological time. The latter of this ascent is continuous and consistent, in spite of the extinction of some groups, the flourishing of others, or the suppressed, covert existence of yet others.

Still, the nature of paleontological documentation is such /95
that even until fairly recently it gave rise to the notion of a discontinuous, highly abrupt pattern of development of life, about periods of flourishing, replaced by universal catastrophes, and mass extinctions. This pattern emerged from a failure to grasp the characteristics of the evolutionary process. Adaptation to conditions of existence by means of natural selection of minor mutations made it possible for certain species of animals or plants (in a different plane, for some of the latter) to flourish and multiply profusely. As a result, the so-called ecological niche, that is, the totality of external conditions of habitat, was populated more and more compactly until this density reached a critical point.

"Niche" is an apt name covering the constraints of a locale, by no means necessarily geographical, but much more often purely biological. Beyond the limits of a niche there was neither food nor other conditions of vital importance for a species adapted precisely to this region. Unlimited propagation resulting from successful adaptation brought about hunger or epizootia and the mass death of the flourishing species. But this same kind of mass death was also caused by small changes in environmental conditions to which the narrowly adapted species with high population counts are highly sensitive.

Mass fatality caused the formation of large accumulations of remains, compelling us to picture monstrous catastrophes. In view of the general spatial dispertion of paleontological documentation, frequent cases appear to be scattered nearly over the entire world. In actual fact, these cases were not at all reflected in other species (except for perishing species associated by a common food chain) and do not at all signify serious upheavals of the entire planet.

Moreover, the steady ascent of historical development from lower forms to higher (regarding the higher forms as more complex and more universal) without a doubt demonstrated the extremely long stability of the environmental habitat on the earth's surface, reflecting the constancy of solar radiation and the quiescent condition of matter in earth's depths. This is especially clear for land organisms not protected by water. To make the journey from the primitive fish-like vertebrates to the higher mammals required about 400 million years. Over this enormous time interval the sun never once "failed to feed" land life. In like fashion, the trillions of kilometers our earth has traveled with the entire solar system through the expanses of our galaxy did not lead to any destructive encounters. Fragile indicators highly sensitive on a cosmic scale -- land, animals, and plants -- indisputably support that by confirming that stars of the type of our sun and systems like our solar system exhibit a stability numbered in the billions of years, that is, they make possible the development of higher forms of life.

A second and very essential fact observed throughout the grand history of life is the directedness of its development. Evolution does not proceed in a single random direction, and adaptation to conditions of existence at each level of geological time (adaptive radiation) spreads only within certain limits. /96
Any substantial perfection of organisms brings about a new "burst" of species formation during which ecological niches are populated by new species, better organized than former species annihilated by natural selection. However, a number of these niches on the earth's surface is limited. As a result, convergence appeared, that is, the adaptation by different organisms of a similar form, similar mode of life, method of nutrition, and pattern of behavior. The similar form of blowholes in groups of marine invertebrates that are dissimilar in origin and epochs of life, the similar structure of free-floating colonies of graptolites and siphonophorids separated by hundreds of millions of years of existence,

and similar forms of trilobites and xiphosurids -- all these are examples of convergence. Or, for example, porpoises are extremely similar to marine crawling ichthyosauri, but appear 150 million years after them. Forms of amphibians similar to snakes existed even in Carboniferous smaller forests about 300 million years ago, while crocodile-like amphibians are of an even more venerable age. Since then, the external appearance of crocodiles has been acquired a number of times in different geological epochs by different groups of reptiles. Modern crocodiles are quite highly organized animals with a nearly four-chambered heart, a complex system of thermal regulation, and with eyes that adapt to day as well as night illumination.

The higher up the ladder of historical development that we climb, approaching our own time, the more frequent and the more profound is convergence. We can recall the fossils of South Africa similar to the principal forms of mammals in the Old World, in spite of the complete separation of the continents. South American ungulates belonging to altogether distinct ancient groups during evolution produced camel-like, boar-like, horse-like, and even trunked species similar to the animals of the Old World. For example, the South American litopterns departed far beyond our horses in foot structure ("unidactylism") but they had a less advanced dentition.

A most amazing animal of South America, found even in very late geological time, is the tilakosmilus, repeating in all its features the structure of the saber-toothed tiger -- Smilodon, but belonging to an entirely different, lower subclass of mammals -- -- the marsupials. The marsupials of Australia also repeated principal groups of higher mammals -- the placentarians of Eurasia and Africa -- rodents, wolves, tigers, and bears.

Adaptations distinguishing entire classes and subclasses in more recent animals emerged as individual features very anciently in the most remote and dissimilar groups. Thus, scorpions appearing 400 million years ago had special sacs at the base of their extremities, in which embryos were attached to a placenta-like formation, this is the high degree of preservation of embryos typical of higher mammals.

Constancy of body temperature, from all available data, appears in the reptiles about 150 million years ago. But in some form, the high energetics of a warm-blooded animal is found in certain fish (of the swordfish or sailfish type), that is, it emerged as a special case in yet very primitive animals. Milk as a substance for suckling young is known in certain birds and even fishes. /97

Finally, recent investigations show that cetaceans surpass man in volume and complexity of cerebral convolutions, but these creatures appeared roughly 15 million years earlier than the primates.

I am presenting only a few examples, and the total number is enormous. It remains only to refer to one of the most typical convergences in land plants -- the biological form of the tree with branches and organs of photosynthesis, and even respiratory roots -- the pneumatophores appearing already at the first stages of development of the large plants.

Over hundreds of millions of years of life plants and animals shared not only similar features of external appearance and the mechanisms of the skeleton or musculature system. Similarities in organs of sense and nervous and hormonal regulation were even closer. Identical features of behavior were elaborated in similar conditions of habitat. These analogous structural solutions show that evolution placed before organisms the same tasks and therefore, has direction. This is how it should be, for the environmental conditions to which organisms adapt existed at the very least for about one billion years.

The energy levels of biological machines -- organisms -- are severely limited. For each stage in the upgrading of the energetics of living creatures no small number of millions of years is required. The energy reserves, let us say, in the liver of a reptile are approximately 1/50-th of that in a higher mammal. Therefore, in the crocodile the duration of a run on land is simply incomparable with the time for which a wolf, lion, or ungulate can run. High energetics, naturally, has a reverse side -- -- food requirements are sharply boosted, life span is shortened, the strain on food chains is aggravated, and expansion and intensification of the food base is required. All this apparently confines and boxes in life with invincible walls of necessity and drives it through the corridor of natural selection. There is /98
only one way out of this corridor -- further perfection of an organism toward greater independence from the environment. Partial adaptation in the history of life on earth is only a temporary success, for which retribution is exacted -- mass death, and later -- extinction when the ecological niche is overpopulated, exhaustion of the narrow food base, or changes in conditions of habitat.

In paleontological burial sites we observed two kinds of animal groups in full accord with the trend of historical development described here. Some, representing the mass of the remains, belong to species that are at times amazing in adaptation, but few in number, identical in the level of evolutionary development. Others, vastly rarer, are distinguished by an outwardly quite ordinary, as it were standard appearance, concealing the height of organization, that is, greater than species contemporary with them and prolific in numbers of individuals. This well known nature of paleontological documentation compelled investigators to suggest that there are two paths of the historical development of life (the evolutionary process): adaptation to local and temporary, particular conditions of life; and a general perfection of an organism -- its growing complexity, universalization of action, and upgrading of energetics and protection against the effects of the environment. The first of these -- adaptive radiation -- continually led animals into impasses, ending with extinction, and the second, called aromorphosis, aristogenesis, or orthogenesis, led to a continuous ascent and the greatest perfection.

It is not difficult to see that actually both "pathways" are only two sides of the same dialectic process in which the great necessity of perfecting an organism is manifest through the sum of the random adaptations. The blind force of natural selection became "seeing" in the sense that it acquired direction continuously operative during the entire course of organic evolution on earth.

The necessity of historical development lies in the acquisition of the greatest possible independence from the environment -- /99
-- the very homeostasis without which information vital to survival could not be accumulated and stored. The "stronger" and more protracted is homeostasis in individual existence, the greater the information accumulated in an individual, the more universal he is, suitable for living in different conditions, and the less he depends on narrow ecological niches. The foregoing does not represent anything new, but when applied to the historical development of life renders understandable and obligatory the appearance of intellect in the higher forms, and the persistent struggle for independence from the habitat that was waged for billions of years by countless generations of plants and animals on our planet. And one more thing -- there could be no premature rational life in the lower forms like molds, fungi, plants, and crabs, and still less a thinking ocean. This, by the way, was known already two thousand years ago. "There is no reason for the unassembled!" exclaims an Indian poet philosopher in the Bhagavagita. "And there is no creative thought for the unassembled...."

In order to visualize the world, one must be able to see and remember all of its exhaustible diversity and, beyond that, even utilize its laws in the struggle for life. Attempts at developing a brain were made more than once in the history of the earth, but they were all premature, because organisms had not yet ascended to the necessary level of homeostasis and energetics. In other cases a brain, even a larger brain that in man, appeared in porpoises and other cetaceans when the total adaptation of their organisms to water precluded a transition to another environment. The making of an artificial environment without the ability of producing implements also became impossible.

Only man himself made his surrounding conditions easier on his life, expanded the food base using fire and the buildup of rational reserves, and thus was able to emancipate himself from his environment to the extent that he could observe, visualize, and subdue the world of his planet.

Man is not characterized by adaptation to any narrow ecological niche -- and in this lies one of his amazing qualities. The life form of man is just as primitive as for his remote ancestors, and it stretches 100 million years deep into geological time. Outward archaicness combines with a high level of physiological organization, energetics, and homeostasis capable of bearing an enormous load -- the brain. The higher the level of organization of life, the more convergent are its forms, and man not only is not an exception, but if you will, the best illustration of this principle. As paleontological data pile up, the "roots" of man stretch still deeper. Today we know of implements even used by protomen (the australopitheci) from strata four million years old. Quite similar forms appeared in various places of the world widely separated, converged, and probably interbred in adjoining regions of habitat, that is, nowhere did they form specialized species, but only subspecies as further stated in the development of brain and labor. Very ancient forms of hominids like Ramapithecus, were discovered in strata 14 million years old. Without a doubt, in the future many other, so to speak, accompanying forms of hominids (like the enormous gigantopitheci, meganthropi, etc.) will be found. Whatever happens, the pathway from protoman to man was not short and reflected the same common principle: the more advanced the development of higher nervous activity, the smaller the "dispersion" of life forms, and the greater their similarity. /100

If we glance over the full diversity of the plant and animal world on our planet, both extinct as well as living today, then we must admit that on the surface of just one planet, in the same phase conditions of the environment, virtually all thinking forms developed, filling all life-suitable ecological niches and regions of habitat. Without tiring the reader with an enumeration, I will point only to clear deviations: the pogonoforids deep within the ocean's depths -- special animals adapted to digest food between tentacles; animals and plants of higher degrees of symmetry -- spheroidal, polyrayed, and pentarayed; sea lilies repeating the form of plants, but equipped with calcareous covering plates and tentacles. In other words, animals so distinct from the bulk of the earth's inhabitants that they could have quite easily appeared on another planet. /101

The abundance of colonial animals -- corals, bryozoans, and siphonophorids is just as strange to us as the freakishly-mechanical organization of the arthropods. Animals as complicated as insects, separated by millions of centuries of development from colonial corals and graptolites, again became a collective organism -- at a new, higher stage of evolutionary development, like ants, bees, or termites.

In general, the history of the organic world honors demonstrates one remarkable feature: the extreme diversity of the lower organisms surpassing our notion of possible forms of life on other planets, and the similarity of higher animals with the repetition of monotypically convergences in sharp contrast with this. If we compare the ladder of life's evolution with Lenin's spiral of development, which essentially it actually is, the spiral will be broad at its base and very narrow at its top. The size of the turns of the ladder become increasingly smaller with time, and the spiral twists more tightly. Is not here reflected some general principle in the development of the universe -- a struggle with entropy enclosed systems? And cannot entropy in this sense play some active role in the development, a role that is still not yet understood by us?

There is no doubt that general laws past and present in the historical development of life on earth are the same on planets of our solar system and remote stars. If we assume with a very high degree of probability that protein-oxygen-water life is the most wide spread in the universe, then we must study our planet as a gigantic laboratory of life's evolution on the pathways of its self-perfection. Actual observations in this laboratory, that is, the study of paleontological documents and their comparison with the biology of now-living forms, will enable us to understand and even predict the course of development in other worlds, which paleontology as a science possessing actual historical documentation has a right to do, if you will, above all other sciences. /102

Today a new stage in paleontology is beginning. Due to the successes of the physical sciences and cybernetics, the feedback of organisms with their environment and the formative role of conditions of habitat no longer are a puzzle for us and the orthogenetic nature of evolution no longer frightens us by the false acceptance of "special" forces. Moreover, we can view paleontology, quite properly, as the key to the future in understanding the causal relationships in the structure of living creatures, and therefore, the problem of the preservation of dialectic equilibrium in the biology of organisms and of all animate nature in general. What was discarded, lost, and what remains have passed the tests of millions of centuries, and above all, man with his brain has resulted, in which we find an increasing number of nerve cells and increasingly complex structure. Latest calculations somewhat exceed the recent figure of ten billion /cells/ and compel us to assume that just the cerebellum, not participating directly in thought, but only controlling the central nervous system, has several tens of billions of nerve cells. The last turn in the spiral of life's development known to us in history proves to be very tightly twisted, and there is full ground to assume that all living creatures in the universe exhibit this same structure.

Hence derives yet another, the last, conclusion. No small number of investigators have assumed that we have no hopes of understanding rational inhabitants of other planets. How can we communicate with them, ask the skeptics, when we still have not yet opened up reliable avenues of communication with each other on our very own planet? This skepticism reflects the theory of "noncommunicativity" of society and individuals now wide spread in the West. Its advocates forget that this is a social phenomenon, and in no way bound to biological features of the human structure. Communication with a rational creature of any other planet, having traversed the inevitable pathway of historical development and acquiring a brain constructed according to the same laws to solve similar problems, of course is possible, just as understanding is possible -- even if not at first on an emotional-social plane -- but in any case -- in the technical-information field. The tremendous convergence and principle of the appearance of the intellect from the primordial chaos of the diverse forms of life on earth gives us a certainty of this.

Thus, paleontology serves as a window into space. Deep within our planet there lies the extremely interesting and puzzling world of extinct life; and by studying it we not only more profoundly understand ourselves, but also are able to predict phenomena in other inhabited worlds not yet accessible to us by extrapolating earth processes of the emergence and development of life.

## ALIEN PLANETARIANS -- ARE THEY LIKE US? /103

Yu. M. Rall', Doctor of Biological Sciences

Rational creatures can scarcely exist on other planets of our solar system. But inquisitive human thought reaches beyond the limits of the corner of the universe where our solar system is.

Can there be, on other worlds, on planets formed around many stars, higher, rational organisms unknown to us? Science fiction writers often describe the appearance of these inhabitants of other planets very whimsically -- in the form of half-beasts, and at times half-monsters. On the other hand, in the science fiction writings of I. A. Yefremov and other authors, rational inhabitants of remote planets are outwardly very similar to man. Who then is closer to the truth?

Man as a product of the development of the animal world is akin to the higher animals (mammals). In order for the gradual transition of these animals to man to have occurred, hundreds of millions of years had to elapse. Just as long a historic past probably was traveled also by the rational inhabitants of other planets before they became disimilar to their immediate animal ancestors.

Hence derived the same prerequisites for the historical development of living creatures on earth as well as on other planets that invariably must lead to similar forms of development.

The closest ancestors of rational creatures must have a highly organized nervous system and its central command post -- the brain. This center must be reliably protected with a skull against any chance stresses. Gravity became evident on a planet and therefore the brain or the organ analogous to it probably is situated in a separate and not too large part of the body free of excess load.

In order to actively adapt to the environment, the rational creature must be able to move in space. This necessitates symmetrically arranged extremities, since a different kind of body would experience overloading on one side. Observing the evolution of living creatures on earth, we know that in all vertebrate animals, in contrast to invertebrates, the number of extremities was sharply reduced over the course of historical development. It has been demonstrated physiologically and anatomically that with a small number of extremities the locomotory apparatus is more projected and more economical. It is not precluded that this kind of evolution occurred also in the rational creatures of other planets.

On planets the force of gravity, just as the pressure of a super-thick atmosphere, can be enormous. In such cases, only very small chances for the development of precursors of rational creatures remain, since their organism must expend the greatest amount of their energy primarily in overcoming these mechanical forces.

If a thinking creature is able to move in space, then in all probability he must have sharply-differentiated frontal and anterior body parts. The sensory organs as the main agencies of perception of external stimuli, in any case the most critical of these agencies, must necessarily be situated in front and close to the center of the nervous system in order that rapid signalling of the brain about the properties of the environment occur along the shortest pathways. /104

The distance to objects can be discerned clearly only when the organs of hearing and of sight are located in a paired stereometric position. It is altogether possible that some inhabitants of other planets have several eyes, principal and auxiliary (many fossil animals, as we know, had parietal eyes).

The laws of refraction of light dictate the inevitability that an optical system formed similar to the arrangement of the eyes in man and higher animals with their color vision. But it could scarcely, however, be that the eyes of other creatures unknown to us are capable of sensing all possible forms of radiant energy -- from long radio waves to cosmic rays. In fact, a creature equipped with such organs would necessarily be able to sense simultaneously definite radiation fluxes penetrating the space around it. In these conditions, life -- let alone intelligent life -- is scarcely possible.

The necessity of an internal support for the body of higher creatures, that is, a skeleton, as well as a vascular system to provide for metabolism in the tissues -- cells of the musculature -- is obvious.

The diversity of the animal world in our planet shows that with a single plan of construction and physiological functions, the outward appearance of species of animals is highly variegated. For example, with the identical plan of construction for all vertebrates there is a great difference between a gopher and an elephant, a shark or a hawk. Each of these animals is adapted to the environment in its own way.

Already based on this experience, we are correct in assuming that even the most advanced animals of other worlds, bearing a general radical similarity between each other in physical structure and, if we assume, the similarity to earthly forms, still do not duplicate each other, as earth animals do not. Therefore, the world of space animals unknown to us not only is variegated, but externally can differ very decidedly from terrestrial life. However, the law of the unity of the physiological functions and the most competent adaptation to the environment must lead to the fundamental outward physical similarity of higher organisms in space.

Let us recall how this occurred during the evolution of the organic world of the earth.

With growing complexity of the forms of terrestrial life, the enormous diversity of lower creatures and the higher-ranking groups gradually became equalized. Thus, while invertebrates, in particular insects, are amazing in the abundance of dissimilar species (they number more than a million!), the appearance of vertebrates, especially land animals, begin to take on some common features. Mammals (they total only 3200 species) are clearly similar to each other, while the external appearance and internal structure of apes and men become strikingly similar.

Along the route of the prolonged development of the higher vertebrates on our planet, cumbersome or overly primitive organs were overcome and discarded through natural selection, and the mass and surface area of bodies were reduced to the optimum correspondence with heat production and heat transfer. Overly large organisms had to expend so much energy in their vital activities that they ultimately were converted into enormous factories for the continuous absorption and processing of food. Possessing a /106
miniscule brain, but giant muscles and stomach, these monsters were swept out of existence by nature. But overly small animals also could not become the starting material for the formation of carriers of reason, since with their tiny energy turnover, they depended too heavily on fortuities of the environment.

Bodily dimensions of the anthropoid apes, and later of man optimally combine the correlations of anatomy and physiology with the requirements of a rational existence in earth conditions, therefore, on any earth-type planet. Of course, these dimensions do not represent an invariant standard, but deviations from them can scarcely be very great.

Thus, by starting from the common ground of the laws governing the development of the material world, we can agree with I. A. Yefremov that the rational inhabitants of the universe are to some extent still "people". They differ somewhat in detail, but have many features in common with us. They can have a different eye shape, a larger or smaller number of digits, a special color of skin, the absence or presence of body hair, and a given head shape. However, there are no grounds to imagine them, as is often done by science fiction writers, as some kind of altogether unusual tailed, horned, multi-handed monsters with an improbable plexus of extremities, leaping, crawling, or even "flowing".

Human fantasy has long since populated planets with strange creatures (an illustration from an 18th century book: Fontenel, Conversations on the Multiplicity of Inhabited Worlds)

Rational life is inseparable from work activity, and the latter encompasses collective interchange. Even F. Engels in his book The Role of Labor in the Humanization of the Ape emphasized that due to this interchange, the capacity to say something to each other developed in formative man. Thus in the course of labor articulate speech took form -- the second signalling system of man, in the expression of I. P. Pavlov. But this is scarcely applicable only to human society. It is more correct to assume that in any rational creatures, both speech and complex social relationships inevitably developed together. What these relationships are we can only guess at, but they must necessarily include the areas of the material productive base of society, the problems of matching productive forces with production relations, etc.

However, it does not at all follow from the unity of the physicochemical laws of space that the universe developed according to a pattern and that the inhabitants of the various worlds only repeat the same history. The same starting conditions can serve as a springboard for an enormous diversity of combinations. Therefore different worlds and different sections of the universe are infinitely varied. But in this infinity there are certain tendencies typical of all moving matter. In much the same way, there is a main line in the development of animate nature that threads through the mass of diverse deviations. With growing complexity of the forms of life, the principal thread brings all rational creatures to the greatest unity with their environment. And since the specific physical environment on inhabited celestial bodies is extremely limited by certain conditions, rational creatures of space must acquire these quite similar characteristics.

## COSMIC INFLUENCES

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"By the environment we must understand all the world surrounding us with its tremendous diversity of various kinds of stimuli."
A.L. Chizhevskiy

Until recently mankind did not fully appreciate the role of cosmic influences on the biosphere of the earth. With the entrance of man into space, not only has a technical, but also a mental revolution occurred in our life. Space has become closer, more reachable. This is the arena in part of present-day, but to a large extent of future activity of mankind, the environment where man will live and work.

Of the mechanisms of the interaction of space and the terrestrial biosphere that are still largely unclear, we can scarcely deny that to understand the role of life in space, its nature, and the characteristics of evolution, allowing for the influences of the space environment is altogether essential.

The articles in this section examine problems of the effect that changes in solar activity have on living terrestrial organisms -- people, animals, and plants; the possibility of predicting abrupt fluctuations in solar activity is taking on vital practical importance. The section begins with an early article by Professor A. L. Chizhevskiy (1897-1964), one of the founders of heliobiology -- -- the science dealing with the influences of solar activity and other cosmic factors on the terrestrial biosphere.

# COSMIC RELATIONSHIPS OF THE TERRESTRIAL BIOSPHERE /108

A.L. Chizhevskiy, professor

Physical and chemical processes occurring in the environment bring about corresponding changes in the physicochemical and physiological functions of a living organism, reflected in his cardiovascular, nervous activity, in his mentality, and finally, in his behavior. Thus, fluctuations in atmospheric pressure, humidity, temperature, amount of sunlight, etc., cause fluctuations in the condition of many functions of our organism, our nervous tonus, being ultimately reflected to some extent in our behavior.

The number of physicochemical factors, as well as the quality of these factors, of the environment surrounding us on all sides -- -- nature -- are infinitely great and diverse. Powerful extra terrestrial forces emanate from outer space. The sun, moon, planets, and an infinite number of celestial bodies are related to the earth by invisible ties. The movement of the earth is controlled by forces of gravity, which induce in the air, liquid, and solid shells of our planet a number of deformations, compel them to pulsate, and bring about the tides. But radiation directed toward the earth from all sides of the universe most strongly affects the organic life on earth.

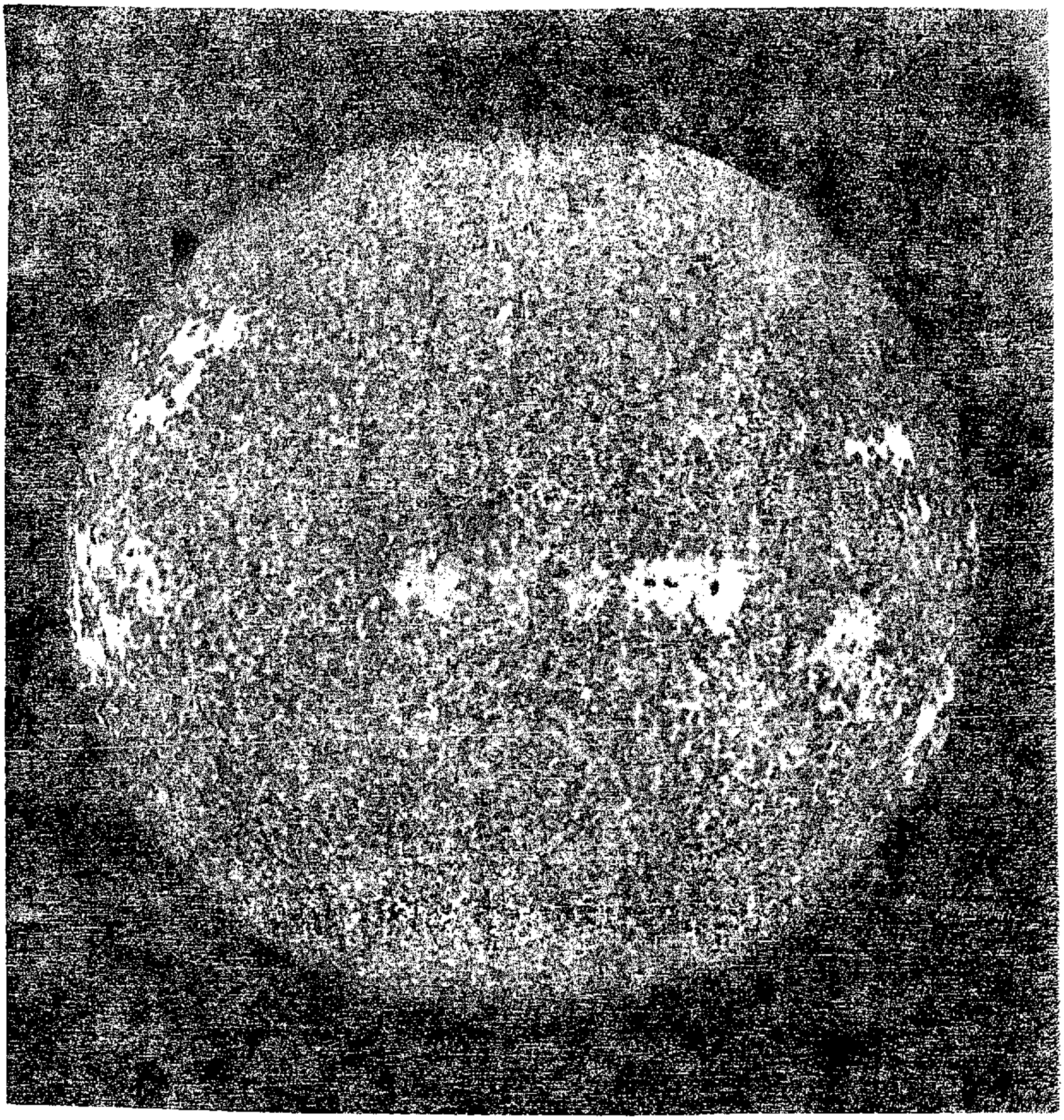
Doubtless, solar radiation, its entire electromagnetic spectrum, and also all its corpuscular fluxes are the principal causative agent for life activity on earth.

Both solar radiation as well as cosmic radiation serve as the primary sources of energy invigorating the surface layers of the globe. The question arises, to what extent does a living cell depend in its physiological life on the influx of cosmic radiation and on the fluctuations or changes that cosmic radiation is subject to.

Extra-terrestrial influences can be studied by using statistical methods. At the same time while observational data made on individuals cannot here provide us with anything reliable, the study of simultaneous phenomena in large masses can lead to discovery of some correlations, reasons for which must then be found.

In 1915 I was the first to formulate this problem and the first to begin studying it. The investigations were extremely difficult owing to a number of circumstances. But still I had the good fortune of discovering a remarkable correspondence between various terrestrial phenomena and cosmic factors.

These statistical studies showed without a doubt that in those years, in the months, and in the weeks when solar activity increases, the number of mass phenomena, for example, diseases, mortality from various reasons, also increases on the earth, in its several continents, and in different countries.

 /109

The sun is the main causative agent of life activity on earth.

For the first time it was found that solar perturbations directly affect the cardiovascular, nervous, and other human systems, and also microorganisms. /110

In spite of the powerful social factors of epidemics, which can be demonstrated with absolute accuracy, one cannot neglect the study of other factors that to some extent can influence the course and progression of an epidemic disease. We can assume that further study of this problem will show what place among the social-economic and biological factors must be given to the influences of the physicochemical environment in general, and to solar and cosmic radiations, atmospheric electricity, and terrestrial magnetism, in particular.

But already at the present time we can state that the effect of social-economic conditions with respect to certain infectious diseases are not of basic importance. For example, influenza epidemics arise very often apart from any specific dependence on social-economic conditions and cover entire strata of populations. In the progression of several epidemics we see the extremely diverse play of the virus and its highly capricious variability over entire decades.

If we assume that during the years of maximum activity the sun produces in outer space certain specific radiations exerting a special influence on the growth of plant tissue, then naturally we can raise the question as to whether these radiations have a similar effect on bacteria as well.

Microorganisms living in a semiliquid or humid environment, in the upper soil layer, on dust suspended in the air, on the surfaces of vegetables and fruits, in decaying organic refuse, etc., can be under the direct influence of specific solar radiations or their terrestrial derivatives, among which there may be fluctuations in atmospheric electricity, certain chemical reactions in the air, etc. Also subject to the same influence are the microorganisms that are concealed in the peripheral parts of the human organism, on the surface of the skin, and on the mucosa of the respiratory passages and the urogenital system.

Starting in 1925, a physician, S.T. Vel'khover, made bacteriological tests for the presence of corynebacteria in material from the upper respiratory passages of patients with infectious diseases in the city of Kazan'. The following method was used: material for the cultures was taken with a sterile swab and then the material was rubbed into bovine blood serum heated prior to the experiment twice to 90° during the period of an hour. After 18-20 hours of keeping the cultures in a thermostat at 37°, bacterioscopy after Neisser was carried out. At the same time, daily observations were made of the trend of meteorological factors in the weather. It was found that the growth of corynebacteria on strictly identical standardized nutrient media intensified abruptly from time to time, yielding in inoculated test tubes the highest percentage of positive occurrences, but no especially close relationship between these sudden increases in bacterial growth and meteorological factors could be found. After carefully analyzing the entire archive of his laboratory from 1926 to 1935, Vel'khover concluded that the intensified growth of cornyebacteria occurs periodically, and these periods have special qualities. If all periods of intensified cornyebacterial growth with a coefficient /112 more that 49 percent are singled out, it turns out that they are constructed in regular harmonic fashion with time. Periods lasting one day are most frequently found. The longer the period, the less often it is encountered. S. T. Vel'khover named the periods in which the corynebacterial growth coefficient was more than 49 percent periods of "major factors" (solar activity was what he was referring to), and subsequently he compared these periods with heliophysical data.

Calculations showed that the periods in which the "major factors" were operative on the average occupied one-seventh of the entire time interval, while in six-sevenths of the entire time interval the growth of corynebacteria was below 50 percent. In this usual time interval the curve of corynebacterial growth varied in zigzag fashion, sometimes dropping down to zero. However, with the onset of the interval of maximum solar activity, the situation changes: the frequency and duration of the periods of "major factors" increase. The parallelism of these curves indicates most strongly the dependence of microbiological phenomena on specific solar radiation.

During the years of minimum solar activity (1932-1934), the intervals between periods of "major factors," as to be expected, were very long and amounted to several months; in the years of a maximum in solar activity (1927-1928 and 1936), the incidence of periods of "major factors" rose sharply.

In his letters of 28 June and 8 July 1936, S. T. Vel'khover told me that based on a large amount of statistical materials, he drew the following conclusion: the incidence of the "major factor" periods corresponds to the relative number of sun spots, and the length of these periods -- to the areas of prominences. And since based on mathematical calculations it is possible, based on the trend of the "major factors," that is, on the growth and coloration of the bacteria, to protect the trend of this phemenon /sunspots/ in the immediate several months or even years, not only micro- /113 biologists or epidemiologists, but also workers in space biology must be interested in this correlation.

Perhaps the time is not far off when we will predict astrophysical phenomena on the sun by studying the variability of microorganisms under the microscope. Already it is clear that some

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Sunspots are one of the principal manifestations of solar activity.

epidemiological and microbiological phenomena reflect, or more properly predict, the manifestation of solar activity. This becomes understandable if we consider that the foci of perturbations arise initially deep within the sun. Neither the eyes of an astronomer nor photographic film respond to them. But the corpuscles, or electromagnetic radiation of the sun, on encountering the living cell of bacteria or the nervous system of man and animals, directly influence them. And only after some time has elapsed are the foci of perturbations displayed on the solar surface and become accessible to visual observation and photography. Therefore, there is nothing improbable in the statement that a microbiological preparation will soon become a sensitive astronomical instrument -- a kind of biotelescope, which will predict certain physical processes on the sun!

Even 30-40 years ago, biologists understood the environment to include basically meteorological and geophysical factors, which in some fashion can influence an organism and cause given reactions in it. The work of I. P. Pavlov includes in the array of environmental factors an enormous number of stimuli surrounding man and influencing his analyzers and central nervous system.

Modern science has very greatly broadened the concept of the limits of the environment, by including in it cosmic bodies sending us electromagnetic waves and particle fluxes. Thus, today we must understand by the term "environment" the entire universe around us with a tremendous diversity of stimuli.

## DEVICE SIMULATING COSMIC RADIATION /112

A special device, the so-called biological unit, has been built in the Soviet Union to simulate the biological effect of radiation in space. Using the biological unit, scientists are attempting to reproduce cosmic radiation that can be encountered by astronauts along their journeys during periods of solar flares.

It has been calculated that about 3 percent of all large solar flares can be dangerous to astronauts. In a year of the quiet sun there are approximately three flares, while in a maximum-activity year -- there are about one hundred.

Cobalt-60 radiation is used in the experiments with the device. The first animals subjected to the simulation of solar flares were white mice. The total radiation dose was 900 roentgens.

The aim of the investigations conducted on the unit was to give an exhaustive answer to all possible variations of irradiation conditions during space flights.

EPIDEMICS IN SUNLIGHT /114

V. N. Yagodinskiy, Candidate of Medical Sciences

In 1610, Galileo Galilei discovered dark spots on the sun. After some time the sharp eyes of Carolus Linnaeus noted a nonuniformity in angular tree rings, and in 1892 Russian researcher F. M. Shvedov, in his work "The Tree as a Chronicle of Droughts," derived this phenomenon as a function of climate. These seemingly disparate facts were brought together by A. E. Douglas, an astronomer and botanist from Arizona, in a series of convincing proofs that the sun's activity influences plant growth.

It turned out that plants record in their growth gains not only climatic fluctuations, but also variations in solar activity, recorded externally by the 11-year cycles of the number of sunspots. "All chemical compounds associated with life," wrote V. I. Vernadskiy, "are collectors of solar energy trapped by living organisms." In confirmation of this we refer to studies by K. A. Timiryazev who established that plants are capable of converting the sun's radiant energy directly into the chemical energy of organic compounds. On the other hand, climatic-hydrological conditions of season and locale governing plant growth in turn also depend on the state of solar activity. V. Yu. Vize wrote in 1945: ".... the fact that a rise in the number of sunspots entails a buildup in general atmospheric circulation, while a decrease entails the weakening of the circulation has long been an established fact." So the dependence of earth's phenomena on cosmic conditions is mediated by a multistage system of relationships and shows up after the time interval required to transmit the influence, and as a result, processes at different levels of biological organization with different responses to natural factors respond differently to changes in solar activity.

We can suggest two ways in which cosmic agents influence a living organism: directly, and mediated by climatic-hydrological conditions (Fig. 1). However, while for the plant kingdom this correlation shows up quite clearly, when we look at complex biological processes, especially in the human society where powerful social forces operate, the effect of the sun's activity is well hidden from the eyes of researchers. Still, even concerning an epidemic process we are correct in proposing the following scheme of the probable influence solar agents have on its progression. Let us try using this working hypothesis to explore the problem that life itself poses.

Any infections characterized by its own mechanism of transmission of the infectious principle (intestinal, air-droplet, transmissive, and contact infections) and can be classified by sources of infection as zoonoses or anthroponoses. The former include animal diseases transmitted to man, for example, plague or tularemia, and the second includes diseases inherent in man. /115

In most zoonoses, the source of human are wild animals, in particular, rodents and blood-sucking parasites inhabiting them. Fluctuations in climatic and feeding conditions of animal habitats lead to changes in their population levels and the build up of epizootias with which a given probability of human infection is associated.

Summing up the data presented by various investigators dealing with "large waves" of the propagation of mouselike rodents in the European part of our country, we can note their confinement to periods of low solar activity (Fig. 2). In the past century, according to the data of K. N. Rossikov (1914), field mice multiplied in Western Europe and in Russia in enormous numbers in 1822, 1832, 1856, 1863, 1867, 1872, 1880, 1884, and 1893-1894. If we compare these dates with the data in Fig. 2, we find that over 140 years mass invasions of rodents coincide in 13 cases out of 17 or somewhat anticipate periods of solar minima, in three cases they correspond to the maxima, and only in one case -- 1863 -- -- is there no relationship. Interestingly enough, phase relationships of solar-biological connections change as we move from one secular solar cycle to another, which has long since been noted even hydrometeorology.

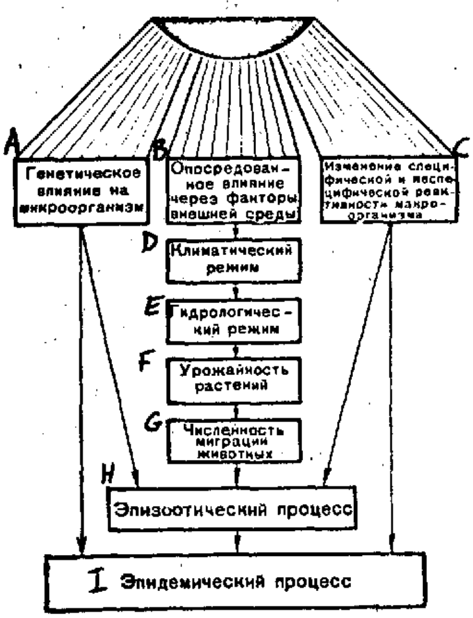


Fig. 1. Possible ways in which solar variables influence an epidemic process
A -- Genetic influence on microorganism
B -- Influence mediated via environmental factors
C -- Change in specific and nonspecific reactivity of a macroorganism
D -- Climatic conditions
E -- Hydrological conditions
F -- Plant productivity
G -- Size of animal migrations
H -- Epizootic process
I -- Epidemic process

But in spite of changes in phase relationships, the correlations of solar-biological connections in certain time intervals are so constant that they can be used in forecasting. For example, P. A. Panteleyev predicted in 1967, based on solar forecasts, the trend in the propagation of the water vole in certain tularemia foci, and this is widely important for even when an effective vaccine is available, the risk of human infection rises (to 80 percent) on specific years of a solar cycle. By knowing these potentially dangerous periods, tularemia preventive measures can be arranged for in advance. In exactly the same way, in spite of the absence in our country of persons affected by plague, constant monitoring of the activity of natural plague foci is essential. In 1966-1969 A. A. Lavrovskiy demonstrated that the most /116 intense plague epizootias in the Caspian foci as a rule occur at solar activity minima, and on this basis, he also predicted plague epizootias in the immediate decades to follow. Thus, study of solar-earth relationships in epidemiology is of great practical interest.

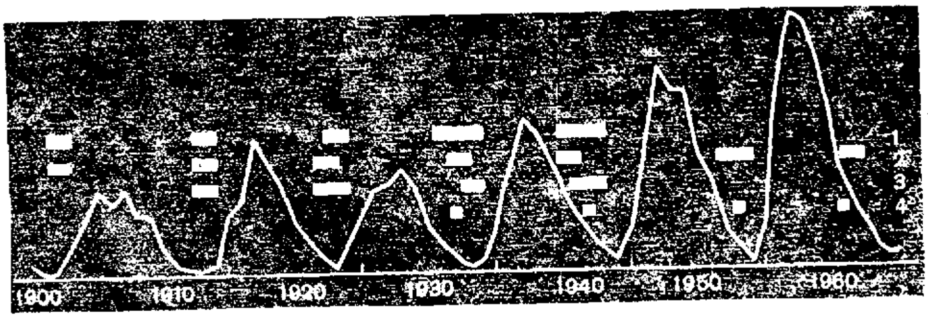


Fig. 2. Periods of mass propagation of mouselike rodents compared with the solar activity curve based on the data of the following:
1 -- Vinogradov and Vashenina
2 -- Formozov and Pilipenko
3 -- Ioffe
4 -- Taurin'sha

A similar mechanism of solar-epidemic relationships sometimes is manifested even during anthroponoses. For example, before the elimination of malaria in our country human morbidity corresponded distinctly to the trend in Wolf numbers (W) with a phase shift of three years, probably required for the solar influence to be manifested in the epidemic process (Fig. 3). This can be due to fluctuations in precipitation enlarging the breeding grounds of mosquitoes, hot seasons accelerating the maturing of parasites in their organism, and also changes in the areal of malaria as a function of periods or warming and cooling. It must be noted that relationships this pronounced with the 11-year solar cycle are seldom encountered in the dynamics of hydrometeorological phenomena, therefore, not only is the influence of cosmic agents on biological objects (man, mosquitoes, causative agent) mediated by natural conditions not precluded, but also the direct influence of cosmic agents on biological material. /117

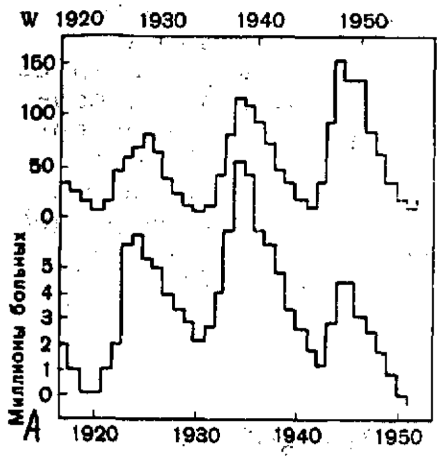


Fig. 3. Number of first-recorded malaria cases in the USSR (after Sergiyev and Dukhanina) and Wolf number dynamics
KEY: A -- Millions of patients

Incidentally, even in the dynamics of an epidemic process, the 11-year rhythm often proves to be strongly masked by other fluctuations, owing to the diversity of factors influencing the trend of an epidemic process. Thus, if we take the data on the dynamics of diphtheria mortality in Denmark and compare them with the trend in solar activity at the first stage we can note a definite correspondence between the sets of data. But after the introduction of sulfur therapy for the infection was made in 1894, there is a marked drop in mortality, and these relationships are broken. Extending observations based on morbidity data, whose indicators are not affected by sulfur therapy, we detect the same correspondence as before, though in a less pronounced form.

All this compels a statistical evaluation of solar-epidemic relationships to be made. To do this, jointly with I. P. Druzhinin, Z. P. Konovalenko, and N. V. Kham'yanova, we interpreted data on the dynamics of diphtheria and a number of other infections in various countries over long intervals of time (up to 100 or more years) using the techniques of autocorrelation and spectral densities. /118

Our analysis showed that the 10-11-year cycle of the dynamics of epidemics is statistically reliable and predominates strongly over the incidence of other periods of fluctuations. Interestingly, among the latter we find the prominent cycle to be the 5-6-year cycle, which is equal to the half-period of solar activity, which for example, in diphtheria dynamics, was found in 32 out of 50 series examined. Similar results were obtained also in analyzing the dynamics of other infections. For example, in scarlet fever the 11-year cycle was found in 90 percent of the cases, and its mean amplitude was 22 percent of the absolute amplitude of the initial series, which is grounds for regarding this variation as major and strongly affecting the dynamics of the epidemic process.

This is quite graphically confirmed by data on the number of deaths per 100 cases of whooping cough (Fig. 4). Against the background of the numerous and dissimilar fluctuations, the technique of the difference of running means was used to "filter" a well-defined 10-11-year harmonic coinciding with the trend in the planetary index Kp of the magnetic perturbation of the earth field, excited as we know by corpuscular solar streams. A typical feature of magnetic perturbations is their buildup and higher frequency not only at maxima, but also at preminima of the solar cycle when there are few spots, but they are more significant for us, since /120 they lie at the sun's equator from whence its emission more easily reaches the earth. Hence the confinement of epidemic surges not only to maxima, but also to minima of the solar cycle and the inception of the 5-6-year rhythm of solar-caused phenomena becomes understandable. Actually, for example, the greatest indicators of the Kp index in Fig. 4 were noted in 1930-32, while the solar activity maxima was in 1928.

There is one more interesting feature of solar activity, which is that over the same cycle abrupt changes occur in the buildup or decrease rate of the number of sunspots. According to the scale of I. P. Druzhinin, this occurred in 1901, 1903, 1905, 1906, 1907, 1908, 1910, 1915, 1917, 1918, 1920, 1922, 1925, 1928, 1930, 1932, 1936, 1940, 1942, 1946, 1948, 1950, 1952, 1956, 1961, and 1964.

Comparing these dates with the points of "inflection", that is, changes in the dynamics of the epidemic process to either side, we get a very well-defined concentration of "inflections" during the years of solar reference points. For example, for chorea morbidity in the USSR, inflections in its trend occurred in 20 out of 26 surviving cases exactly at the points of abrupt changes in solar activity; this is grounds for asserting that the relationship actually exists, with a probability higher than 99 percent. Overall, by making a statistical evaluation using the "chi-square" method, we obtained these results. When the dynamics of ten mass infections in different countries were investigated, in which the total number of years examined was 4750, the probability of chance for differences in the frequencies of inflections in epidemic trends during the years of abrupt change in solar activity and in all other years was less than 0.01 percent.

Hence it follows that during a single 11-year cycle in the dynamics of an epidemic process, there is a "breakdown" of the cycle into several smaller fluctuations and thereby the main 11-year trend in the epidemic wave is masked. Probably, some of the /121

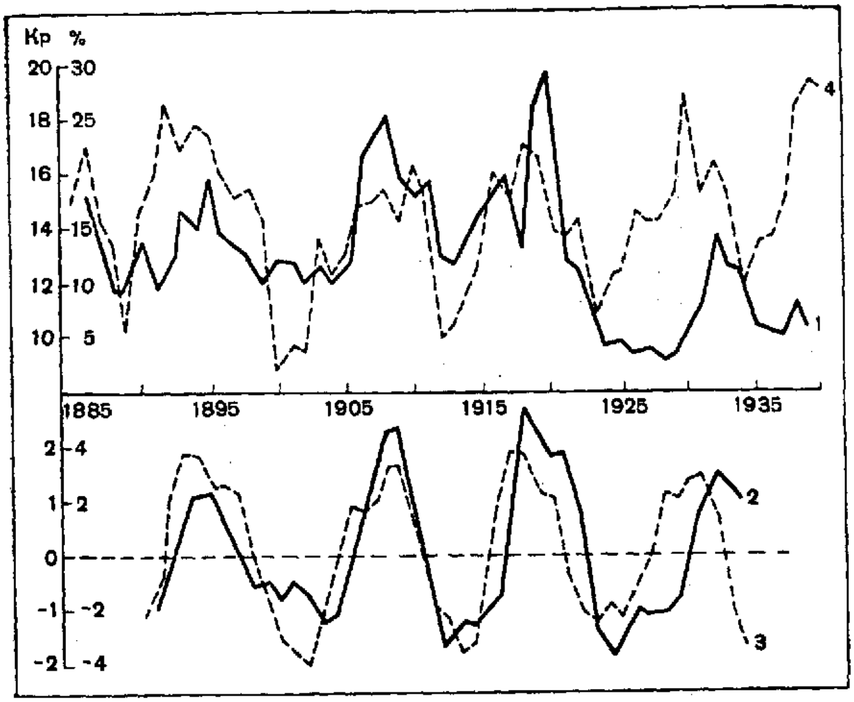


Fig. 4
1 -- Curve of mortality from whooping cough in Moscow
2 -- Its modified curve with periods shorter than 5 and longer than 14 years excluded (this is done by subtracting the 11-year running means from the 5-year running means)
3 -- As above, for the dynamics of the planetary index of magnetic perturbation Kp (4)

epidemic process cycles lasting 2-4 years (44 percent from our data) can be classified as similar "periods" in the alternation of solar reference points.

What are the explanations of this dependence, besides those advanced earlier concerning natural-focal diseases.

First of all, since an infection is the result of the introduction into an organism of bacteria or viruses, we must trace the influence of helio-geophysical factors in their life activity. This was done for the first time in 1935 by S. G. Vel'khover, who published the results of nine years of work with corynebacteria, which includes the diphtheria causative agent. During the observational period, a buildup in their growth and changes in their biological properties beyond the 49 percent level of deviations from the former state agreed closely with solar activity dynamics. For example, after the 1927-1928 solar activity maximum 36 and 25 abrupt changes in microbial properties were recorded, respectively, while at the 1933 minimum there were only seven deviations from the former state.

Interestingly, some rise in the frequency of microbiological changes were detected also during the years of especially intense magnetic perturbations at the solar cycle preminimum. In contrast, a laboratory diphtheria culture stored in a lead cylinder changed its properties only nine times during the entire 9-year observational period.

This can be compared with the experiments of G. Vil'dfyur (1957) who observed seasonal fluctuations in the virulence and toxin formation of microbes with acceleration in their multiplication and with in crease in resistance to destructive factors, as a function of the time of the year. But perhaps of greatest interest is the variability in the influenza virus, which is one of the factors behind changes in the epidemic process.

On first acquaintance with the history of influenza epidemics (Fig. 5), it is hard to discern any system in their inceptions: the intervals between influenza outbreaks range from 2 to 5-6 years, while the period of abatement between the 1899 and 1918 pandemics lasted for more than 20 years. And the first world wide epidemic emerged against a background of relatively stable social conditions, while the notorious "Spanish flu", taking 20 million lives, climaxed World War One. /122

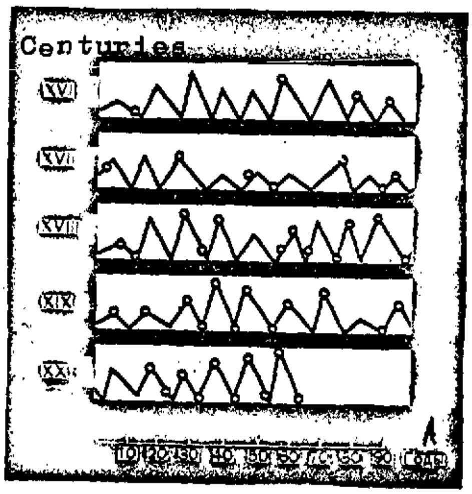


Fig. 5. Initial dates of epidemic influenza cycles (circles) and solar activity curve
KEY: A -- years

To find the periodicities influenza, we made a spectral-analysis of one of the reliable sets of statistics -- influenza mortality in Great Britain and Wales over a period of 107 years. The harmonics of 2, 11, and 16-20 years prove to be the strongest in incidence. The first probably corresponds to fluctuations in the immunity level of the population, while the 16-20 year harmonics can be linked to similar geophysical cycles noted by numerous researchers, and this is not surprising for weather changes play a key role in the distribution of influenza epidemics. The 11-year cycle is most likely a reflection of solar influence.

Actually, after examining the times at which influenza virus variants appeared and circulated, we are struck by the similarity of the periods of their active circulation with fluctuations in solar activity (Fig. 6). Thus, the nearly continuous series of epidemics caused by the A-1 virus since 1947 was displaced by the cycle of pandemic spread of influenza at the maximum of the secular and 11-year cycles of solar activity in 1957, caused by the appearance of the A-2 influenza virus for the first time in history, to which the earth's population was defenseless. As to be expected, some changes in biological properties of the virus occurred also during periods of solar activity minima when there was a rise in magnetic activity, which was reflected also in the spread of epidemics. For example, large influenza epidemics were observed near the solar cycle minima -- in 1952 and 1962.

There is full reason to assume that the change in the variant array of influenza viruses is related to some elements of solar emission, called the "Z-factors" by A. L. Chizhevskiy, however at /123 the present time it is difficult to establish their specific content without conducting appropriate experiments, though in artificial conditions it was shown that nearly all agents of silver radiation have pronounced biological and mutagenic effects.

A real contribution to public health practice will be epidemic forecasting. Short-run forecasts are based on ordinary epidemiological factors, such as the rate and possibility of the penetration of patients into a given locale during the recording of the condition of immunity, weather forecasts, etc. A prediction of this kind concerning influenza, but with reference to solar disturbances causing stormy perturbations in the atmosphere was published by us on 16 November 1966. An epidemic broke out late in 1966 and reached its maximum early in 1967. In 1966 we published also a long-term forecast of an epidemic expected in 1968-1969. This prediction was entirely borne out by a series of epidemics caused by a new variant of the influenza virus, the Hong Kong virus, which in 1968 spread from Southeast Asia and reached the USSR in early 1969.

We have dwelt in detail on the relationships between the change in the variant composition of causative agents of infectious diseases and the condition of solar activity because the question is the least studied problem area, and one that is most vital not only with respect to influenza. For example, during outbreaks of dysentery in our country at the 1957 solar activity maximum, the morbidity was 25 percent higher than in the adjoining years of

1956 and 1958. A similar situation occurred at the current maximum, related to the involvement in the epidemic process of the Sonne dysentery causative agent biologically distinct from earlier variants in circulation. This example also shows that periodicity is inherent not only in infections with the air-droplet mechanism of causative agent transmission, but also for intestinal infections. Additional proof of this can be found in the cholera epidemic /124 progressing in the past decade, involved with the wide propagation of the El Tor vibrion, which was earlier limited only to local outbreaks, but has now displaced "classical" strains of the cholera vibrion even in India.

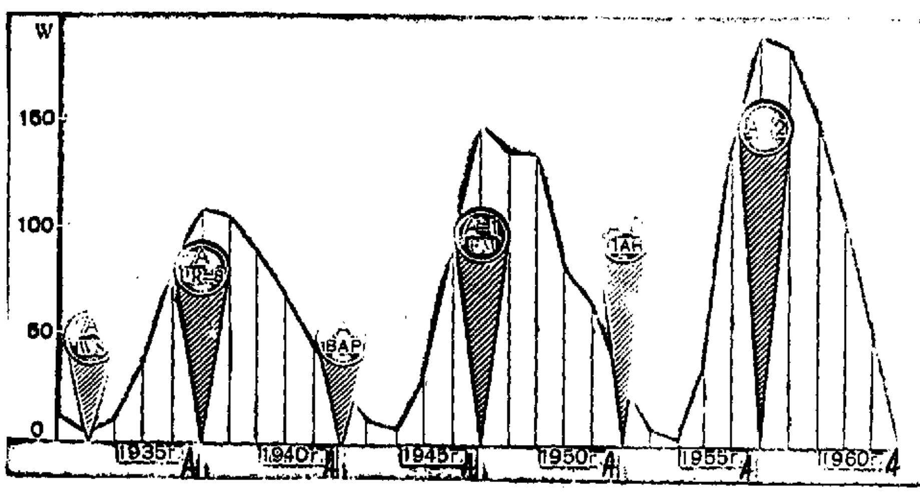


Fig. 6. Appearance of new influenza virus variants as related to characteristic periods of solar activity
KEY: A -- year

However, the effect of microorganism variability on the trend of the epidemic process can be manifested only in interaction with the human organism and only by activating its mechanism of transmission.

The role of various kinds of solar radiation for the human organism is clearly shown by various aspects of regional and general climatophysiology. The studies of N. A. Shul'ts and V. A. Kozlov present proof of changes in the composition of blood -- the carrier of an organism's protective forces -- as a function of the phase of the solar cycle, its aperiodic and seasonal variations, and geographical latitude. N. V. Vasil'yev suggests that the action of magnetic fields on the immunological disposition of an organism is associated with the sensitivity of immunocompetent tissues to these field, in particular, marrow, which has in fact been detected in appropriate experiments. Moreover, the role of ordinary climatic factors in forming human predisposition to infection is well known.

Of course, all these questions deserve detailed study and some of the hypotheses we have raised require experimental testing.

## Some Conclusions

The dependence of biological phenomena on cosmic forces evidently is a universal principle. In this respect the epidemic process is a good model, since it encompasses in its orbit all elements and levels of biological systems, beginning with the virus and with plants and ending with the human organism. Here we must emphasize that all changes in the epidemic process are a consequence of social and natural influences on the source of an infection's causative agent, the avenues of its transmission, and a susceptible population. Systematic changes in an epidemic process are formed by social influences, while periodic fluctuations in the process are caused by natural factors which have the property of undergoing periodic changes -- change of day and night, seasons of the year, solar and lunar rhythms, etc. Fluctuations in solar activity are most significant for multiannual cycles in biological processes.

In confirmation of this we can refer to advances made in studying numerous processes in the biosphere related to cosmic factors. Thus, K. F. Novikova, A. P. Shushakov, and B. A. Ryvkin, in collaboration with heliogeophycists (L. A. Vitel's, M. N.Gnevyshev, A. I. Ol', and others), drew up practical recommendations on preventative measures for myocardial infarct and cerebral insult with reference to solar-magnetic changes. Variations in blood composition as a function of cosmic causes, as shown by N. A. Shul'ts, A. T. Platonova, and V. A. Kozlov, are so significant that the results of their work has already been reflected in /125 the theory and practice of hemotology. Also approaching practical application are the experiments of A. K. Podshibyakin comparing the kinetics of human skin electropotentials with heliomagnetic factors. Also vital are the observations of V. P. Desytov, who noted a relationship between mortality and accident frequency and ionospheric disturbances. This author's observations were made under the influence of the work of the oldest enthusiast of cosmic biology, P. M. Nagorskiy, who carried out following A. L. Chizhevskiy a series of experiments on shielding biological materials against cosmic radiation. Overall, all these studies confirmed the results of the pioneering work by A. L. Chizhevskiy who was the first to validate the hypothesis of the diverse influence that cosmic agents have on the earth biosphere.

Perhaps there are not yet sufficient factual confirmations of the reality of sun-earth relations in all fields of science, but we must bear them in mind, since for example well-defined statistical relationships between solar activity and oncological morbidity presented in 1968 by I. V. Galaktinova and S. N. Kupriyanov show the promise of research in this direction.

Solar-biological relationships are interesting not only as applied to medicine. Work done by I. B. Birman revealed that there is a complex, but quite well-defined dependence of fish hauls on solar "weather". The research done by N. S. Shcherbinovsky on predicting locust invasions associated with the 22-year solar activity cycle have already become classic. Changes in the populations of commercial species of animals and of agricultural pests as a function of solar cycles can be of great value, in particular based on the data of E. Ya. Taurin'sha and A. A. Maksimov, in forecasting. Feeding conditions for animals are determined by plant productivity. Judging from historical data given by T. V. Pokrovskaya and N. I. Knyaginichev, very poor harvest years were observed at specific solar activity periods, for example, in the central belt in 1881, 1891, 1901, 1911, 1921, and 1932. Today due to advances made in farming and the planned management of agriculture, solar-harvest relationships are much weakened, but the potential for poor harvests rises in certain periods of the solar cycle. Therefore, hoof and mouth epizootias, equine encephalomyelitis, hog cholera, and anthrax prove to be linked with solar rhythms, as shown by K. A. Dorofeyev and others.

We could cite a great many more arguments and facts in favor of the necessity of expanding research in heliobiology. But what we have said is enough to convey the thought that the country where heliobiology was born will gradually become the center of its further advances.

# HELIOBIOLOGY /116

V. V. Parin, Academician

In recent years yet another field of human knowledge -- heliobiology -- has achieved deserved recognition: it is the science of the influence of solar activity on the earth's biosphere. The importance of heliobiology was not understood for a long time mainly because many biological characteristics of an organism must be examined from certain physical and chemical standpoints. Advances in modern biology require growing interdisciplinary approaches in studying phenomena of life. These investigations not only promote greater publicity to new fields of knowledge, but also bring significant theoretical and practical results.

THE SUN IS GUILTY

V. Desyatov

On the advice of Academician V. I. Vernadskiy, already in the 1930's Tomsk biologist P. M. Nagorskiy undertook many experiments to study the effects cosmic factors have on living creatures. He dissected jellyfish, planaria, water fleas, and tadpoles and placed them in a chamber with six lead walls. Regeneration occur- /117
red much faster in the chamber than in control experiments outside the chamber. The dissected jellyfish and tadpoles recovered splendidly. In his other experiments colonies of microbes on nutrient media placed in a lead chamber showed vigorous growth compared with the control. Nagorskiy concluded that even partial restriction on exposure to cosmic energy intensifies the vital activity of protozoa and microbes, and even alters their pathogenic qualities. In other words, the conditions of life on earth are not optimal for them. By varying the dose of given kinds of solar energy, one can control the vital activity of the inhabitants of our planet. We made a systematic study of the relationship between solar activity and severe cases of illness, guided by the following working hypothesis. The sun sends streams not only of useful, but also of harmful radiation. True, life on earth is protected by a "screen" -- the ionosphere. But the condition of the ionosphere depends on solar activity. During solar flares the protective screen of the earth -- the ionosphere -- is disturbed and cosmic radiation penetrates into the biosphere more deeply, more massively, and at times influencing all of life very /118
strongly.

In days following solar flares the frequency of severe cases of disease is much higher than on quiet-sun days. It is particularly high on the second day after an intense solar flare, and the highest incidence was noted during the years of the quiet sun (1952, 1953, 1954, 1963, and 1964). It is possible that during the years of the "stormy" sun persons develop some adaptation to solar flares. But during years of the quiet sun persons suffering from atherosclerosis and hypertension prove to be unprepared for the next flares.

What then is the mechanism by which solar activity influences the human organism?

As we know, nerve endings respond to a negligible amount of energy, sometimes ten-billionths of an erg. During solar flares fluctuations in energy reaching the earth's surface amount to fractions of an erg per square centimeter per second. It stands to reason that a highly organized central nervous system in whose activity energy processes play no minor role cannot remain indifferent to changes in solar activity. Stimulation of the central nervous system, including the so-called bulbar center of the vagus nerve, which according to I. P. Pavlov is the most efferent nerve of the heart, leads to a change in cardiac activity. A healthy heart copes with this situation painlessly, but a sick heart -- with difficulty.

Of course, our explanation needs experimental and clinical testing.

Our observations on suicides and automobile accidents are revealing. It turns out that persons with a weak type of nervous system, and also chronic alcoholics feel extremely depressed after solar flares. As a result, the number of suicides on the second day after solar flares rises by a factor of 4-5 compared with quiet-sun days.

Reasons for suicide which seem to be slight on quiet-sun days appear insurmountable on days following solar flares. The number of automobile accidents on the second day after solar flares also rises sharply -- by nearly a factor of 4 compared with quiet-sun days.

Here is a table confirming this hypothesis.

| Year | No. of accidents<br>Total days<br>1st day | <br><br>2nd day | <br><br>3rd day | Quiet-sun days | Ann. mean |
|---|---|---|---|---|---|
| 1958 | 0,10 | 0,20 | 0,08 | 0,09 | 0,12 |
| 1959 | 0,11 | 0,21 | 0,04 | 0,03 | 0,10 |
| 1960 | 0,11 | 0,21 | 0,11 | 0,09 | 0,13 |
| 1961 | 0,16 | 0,31 | 0,16 | 0,09 | 0,18 |
| 1962 | 0,19 | 0,36 | 0,18 | 0,06 | 0,20 |
| 1963 | 0,40 | 0,15 | 0,18 | 0,08 | 0,12 |
| 1964 | 0,13 | 0,29 | 0,16 | 0,07 | 0,16 |
| Mean | 0,14 | 0,25 | 0,14 | 0,07 | 0,14 |

As we can see from the data, a statistically reliable difference shows up quite sharply.

K. Werner in Hamburg and R. Reyter in Munich, just as ourselves, reported an abrupt increase in the number of automobile accidents, based on a great deal of material (about 100,000 accidents), on the second day after a solar flare. In 1954 and 1955 Reyter recorded a delay in response to signals amounting to a factor of four found by automatic recording during solar flares, compared with responses during quiet-sun days. The goal of all these studies is to strive for human longevity. If our conclusions are finally confirmed, this means that preventive measures are necessary. If astronomers were able to predict in time days of sharp increases in solar activity, doctors (given their present arsenal of ways of working for human health) would be able to take the required steps in time. Automobile inspections would then protect drivers against possible accidents.

Here we must note that days of glazed frost and fog show nearly no increase in the number of highway accidents, since on these days drivers are more cautious.

The accumulation of new data on the effect of solar flares is also necessary for the comprehensive training of astronauts for flights in the solar system.

We are convinced that in the future (of course we do not know whether in the near or distant future) periods of the quiet sun must be chosen for launches of interplanetary passenger rockets.

# IN THE SUN'S RHYTHM /126

A. K. Podshibyakin, Doctor of Medical Sciences

Fluctuations in solar activity have been found to be reflected in numerous earth phenomena. S. I. Kostin, for instance, examined climatic fluctuations on the Great Russian plain over the past 4,000 years by measuring the thickness of ooze deposits laid on the bottom of lakes in Southern Karelia and the Crimea. The thickness of ooze deposits, as we know, depends on hydrometeorological conditions. This afforded the conclusion that years with thickest and least thick ooze deposits corresponded to years with greatest and smallest amounts of annual precipitation.

The mean interval between extrema in the annual ooze deposit thickness was close to 11.3 years. Thus, a relationship was found between climatic change, lake deposit thickness, and the 11-year cycle of change in solar activity.

The salinity of the Baltic Sea, the water level in the Caspian Sea and in Lake Victoria, ice conditions in polar seas, and river highwater and migration change in accord with solar cycles. The intensity of the northern lights, the perturbation of the earth's electromagnetosphere, and other factors on which radio communications depend vary in relation to the condition of the sun.

Even the condition of colloids and the rate of certain chemical reactions are determined by the condition of the sun.

There is a well-defined relationship between the freezing point of small amounts of supercooled water, the intensity of sunspot forming processes on the sun, and the perturbation of the earth's magnetic field. It is natural to expect that all these phenomena and facts, especially changes in the properties of colloids and water, are reflected also in the earth's biosphere. In fact all of life to some extent involves aqueous solutions of protein, colloids, and salts.

Accordingly, investigations confirming these functions are of great interest. To illustrate, R. L. Berg showed the planet-wide increase in mutations in drosophila flies coinciding with a buildup in solar activity. N. V. Shul'ts revealed a relationship between functional leucopenias and the sun's cyclic activity. A. I. Gartman found the same to be true about relative lymphocytoses. A similar dependence in fluctuations in the level of neutrophil leucocytes and in the absolute number of eosinophils in human blood over the 11-year solar cycle was shown by V.A. Kozlov /127
and a group of coworkers.

From the data of V. V. Kokhanovskiy and F. F. Morozov, the buildup and decline in systolic pressure and in cardiac output follow a rise and a waning in solar activity. Sistolic pressure during the first half of the solar cycle (from 1954 to 1957) rose markedly (by an average of 10.4 ± 2.17 mm Hg in young men, and by 7.3 ± 0.98 mm Hg for young women). The diastolic blood pressure rose more sharply during this period, and when the solar activity maximum was passed in 1957-1958, it again began to drop.

Data are available indicating the effect of the 11-year solar cycle on several biophysical, more correctly, electrical processes in human skin.

Electrical potentials of human skin reflect certain biophysical and biochemical changes occurring both in the skin itself as well as in the organism as a whole. Their changes are brought about by electrochemical characteristics of intracellular active proteins. But if we take the arithmetic mean of the electrical potentials of the skin over a period of a month for a group of persons and compare them with the mean-monthly Wolf numbers (that is, with the numbers characterizing solar activity), we can find some relationship. In 1947-1948 and in 1957-1958 solar activity reached a maximum. In 1953-1954 and in 1964-1965 it fell to a minimum.

It turns out that during the periods of solar activity maximum the electrical potentials rose, while in the minimum period, conversely, they declined. As the figure shows, extrema of the mean-monthly static electrical potentials and the mean-monthly Wolf numbers (W) coincide.

We know that the condition of the earth's magnetic field fluctuates in relation to solar activity.

V. Tsiran, in analyzing data on the beginning of birth labor and comparing them with the condition of the earth's magnetic field, stated that labor begins less often during times of sizeable magnetic storms. Nature apparently does not allow a human birth in inclement magnetic "weather".

R. Reyter found that during chromospheric flares of the sun, human response to a signal is slowed down by nearly a factor of four. He also noted a pronounced relationship between the time phantom pains start up and intensify, a deterioration in the condition of patients following brain operations, and chromospheric flares on the sun. Based on analyzing 150,000 accidents and disasters, R. Reyter discovered that they occur most often on days with sizeable perturbations on the sun.

V. P. Desyatov, using forensic-medical material from 4,000 accidents and sudden deaths, found a definite relationship between fatalities and solar condition. On days of solar perturbations, fatalities rose by a factor of 1.5 compared with indicators on "quiet" days.

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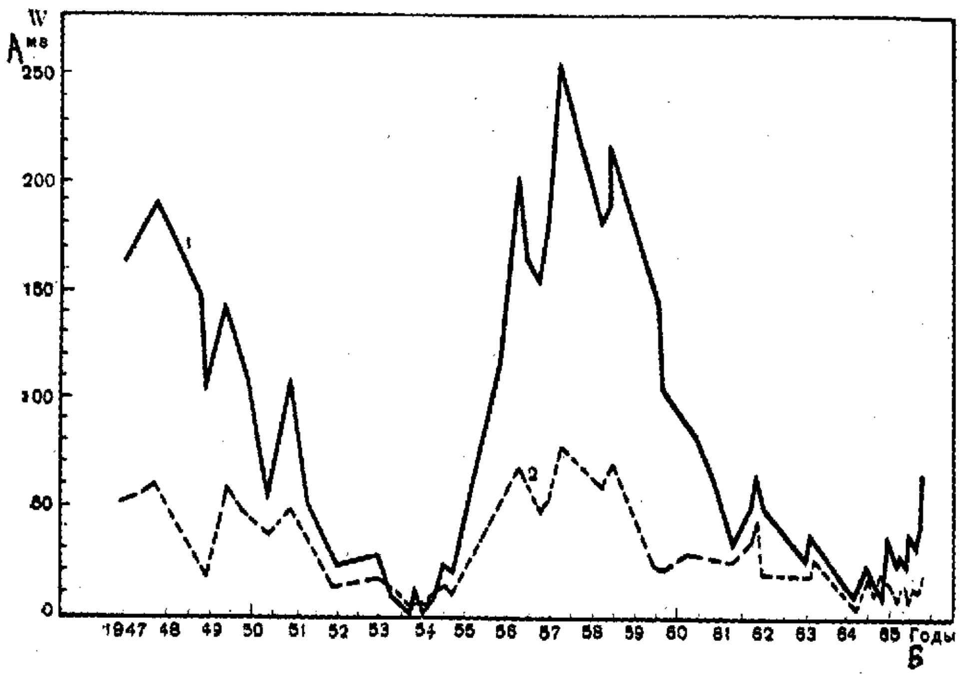



Changes in mean-monthly Wolf numbers (1) and mean-monthly static electric potentials of human skin (2)
KEY: A -- mv
B -- Years

R. Martini examined 5,580 accidents occurring in coal pits of the Ruhr. He found that their frequency increases strongly on days of geomagnetic storms and on days when a large group of sunspots travels across the sun's central zone. The reason for this, in the view of A. L. Chizhevskiy, can be a decrease in the volitional qualities of an individual and a rise in his excitability. The statistical analysis we made showed that on days of geomagnetic storms dogs show an increase in their variability of conditioned food reflexes and a unleashing of differentiation, in turn leading to changes in the analytical-synthetic functioning of the brain, that is, dogs "imagine more poorly" what they can and cannot do.

In 1962 M. Pumaiou /transliterated/ and R. Viart pointed out that during pronounced geomagnetic storms the condition of cardiovascular patients deteriorates and their fatality from myocardial infarct climbs. An analysis of this finding made by K.O. Novikova,

T. N. Panov, and A. N. Shushakov on 455 patients with true myocardial infarct revealed an interesting dependence. It turned out that the number of cases rose in proportion to the perturbation of the earth's magnetic field.

B. A. Ryvkin examined 2,305 cases of myocardial infarct occurring in Leningrad in 1963. He found that on days of high solar activity and thus days of geomagnetic storms, the mean-daily number of myocardial infarcts rose. And during the acute period of the disorder 85 percent of the fatal outcomes occurred during a time of high solar activity. /129

We also made a preliminary analysis of morbidity and mortality from myocardial infarct observed in Kiev in 1966. Out of 1,585 cases of myocardial infarct, 75 percent began either one day before a magnetic storm, during the storm, or one day after the storm. Typically, during these days myocardial infarct morbidity was more pronounced in March -- 77.2 percent, and 100 percent -- -- in September, while mortality was 87 percent and 100 percent, respectively. On the other hand, in May the correlation between morbidity and magnetic storms was only 40.4 percent.

Examples of the effect of changes in solar activity (corresponding to changes in the condition of the earth's magnetic field) on the functioning of the cardiovascular system can be supplemented by other data as well.

The erythrocyte sedimentation rate (ESR) in the blood of healthy dogs (based on the data of V. P. Kolodchenko, 1968) correlated rigorously and reliably with the perturbation of the earth's magnetic field. During magnetic storms the ESR accelerated, while after they passed -- declined.

In some dogs (especially those weakened by operative intervention associated with making a second, Pavlovian, stomach), comparison of the acidity of gastric juice and its amount with the horizontal component of the earth's magnetic field revealed some signs of a relationship. The stronger the magnetic field perturbation, the lower was the gastric juice acidity.

This fact is of interest as an extension of the ideas of A. L. Chizhevskiy stating that during periods of greater solar activity (and thus of more frequent and abrupt perturbations in the earth's magnetic field), the number of gastrointestinal disorders rises. Hydrochloric acid contained in gastric juice is the main barrier that prevents the penetration of pathogenic and other bacteria from the environment into the lower levels of the gastrointestinal tract. With a reduction in the amount of hydrochloric acid, which is observed in some cases when there is a rise in solar activity, the protective functions of the gastric barrier are weakened. This naturally can produce conditions for the penetration of various kinds of bacteria into the intestine. /130

As early as 1924, A. L. Chizhevskiy wrote about the effects major storms on the sun have on the neuropsychic sphere of neurotic and mentally ill patients. This shows up, in his words, in the derangement of self-awareness, in disturbance of volitional actions, in sharply pronounced emotional excitability, etc. In 1930 he noted that not only patients, but also healthy individuals are not free of the effect of changes in solar activity. Further investigations revealed that human group responses to helio-geomagnetic disturbances actually exist.

If we take static electrical potentials of the skin measured each day to evaluate human responses to helio-geomagnetic disturbances, and throw out the extreme variants of these reactions, we can isolate two groups of persons: those predominantly magnetostable and those predominantly magnetomobile. In terms of characteristics of nervous activity, magnetostable persons are marked more by a phlegmatic nature, equanimity, calmness, persistence, and tenacity in work compared with magnetomobile persons.

Maximum values of static electrical potentials in magnetostable persons were observed more distinctly a day before and a day after a magnetic storm. In magnetomobile persons maximum increments in static electrical potentials were noted four days before a magnetic storm and on the day of the magnetic storm. During these days the coefficients of the correlation between perturbations in the earth's magnetic field and arithmetic means of static electrical potentials was most significant.

Thus, the effect of outpacing geomagnetic perturbations has been detected in man. This effect shows up more clearly when changes in the asymmetry of the distribution of static electrical potentials over the skin of the head are observed. In a virtually healthy individual, there can be negligible asymmetry in the static electrical potentials on the skin of the right and left halves of the head. In patients this asymmetry can be appreciable. An increase in asymmetry in magnetomobile persons is noted chiefly four days before a magnetic storm, while only two days before a magnetic storm in magnetostable persons. Correlation coefficients on these days are higher compared with other days. /131

To understand the effect of outpacing, we can start from the fundamental of two assumptions: selective sensitivity of living organisms to very slight energy influences and the different rates at which solar material is emitted in the zone of the earth.

As an example of selective sensitivity, we can present only the well-known facts that some patients (affected with rheumatism, bronchial asthma, etc.) can judge future weather changes several days in advance by how they feel. There are a good many data indicating that long before an earthquake, storm, or a cold or warm winter animals respond to it in distinctive ways. It is not precluded that even in man, in spite of the specific ecological conditions of his life, there still remains some qualities of the "premonition" of possible perturbations in the earth's physical fields.

The second hypothesis to explain the effect of outpacing geomagnetic disturbances can be related to the different rates at which solar material is introduced into the zone of the earth. Simple mathematical calculation shows that distance from the sun to the earth (about 150 million km) is covered by electromagnetic waves in about 8 minutes. A corpuscular stream, which is the "culprit" of disturbances in the earth's magnetosphere, is characterized by different velocities. At a speed of propagation of the /132
order of 1,000 km per second, it covers this distance in about 8 days.

From the calculations of A. B. Severnyy, the beginning of magnetic storms is delayed by an average of 26 hours compared with the time of passage of sunspots across the sun's central meridian.

Thus, an increase in static electrical potentials and a rise in their asymmetry of distribution by about 2 days before a magnetic storm becomes more understandable. It can be caused by the electromagnetic influence of the sun. As for the increase in potentials and the greater asymmetry in their distribution for days ahead of the storm, the mechanism of this effect is unclear and needs further study and analysis.

* * *

From what has been said it is clear that a knowledge of human and animal responses to helio-geophysical perturbations even now can be serious practical importance. We must give thought to setting up a special sun service that would report to workers in transportation, medical, and other establishments about possible helio-geophysical disturbances and that preventing various kinds of accidents in production, complications in patients with chronic disorders, and other pathological effects.

Man needs a clear idea of the sun's role in the life of the earth in order to know what to guard against and what to use and how to use it, and with what he must cope with to the measure of his abilities.

# THE SUN AND US /129

A. T. Platonova, Doctor of Biological Sciences

In recent years heliobiological studies have drawn growing attention from the broad medical community. In Leningrad and Moscow, in the Caucasus and in the Crimea, in Sverdlovsk, Irkutsk, and other cities the effect of changes in solar activity on the incidence of infarcts, hypertensive crises, and various manifestations of nervous disorders are being studied. In most cases more or less well-defined correlations have been found.

These investigations have been carried out by our heliobiological group at the Institute of Earth Magnetism, Ionosphere, and Propagation of Radio Waves, of the Siberian Division of the USSR Academy of Sciences. Based on a wealth of material covering the entire cycle of solar activity, we have shown the effect solar flares and magnetic storms have on human health.

Magnetic storms are of special interest. They occur in different ways. Specialists classify them into storms with sudden and gradual onset. Both kinds can be weak, temperate, intense, and very intense. It turns out that storms with sudden and gradual onset act differently. Interesting data has been gathered /130 for different days of the storm, and also for days before and after a storm. The fact that the magnetic field influences life at present is beyond doubt. But here there are still many questions which must be analyzed in detail. We are now entering the field of magnetobiology.

All heliobiological research undertaken thus far has been principally statistical. A given "indicator" was studied and its changes were compared with solar activity. These studies are of definite interest, but they do not answer the question as to the mechanisms by which changes in solar activity affect life. Moreover, to be masters of the situation, we must utilize changes in the sun to the maximum in the interest of mankind and reduce their harm to the minimum; for this purpose we must know clearly how and by what mechanisms life is affected by these changes. The avenue to comprehending the principles is broadly pursued laboratory experiments in which individual kinds of solar activity are simulated.

Living creatures are capable of tolerating within certain limits changes occurring in their environment. Within these limits metabolic processes in living organisms proceed normally.

Here numerous adaptive or as they are so called, compensatory reactions come to their aid. But while compensation is very good in a healthy organism, during various disorders it is weakened to a greater or lesser extent. And this means that a sick organism is much more sensitive to changes (even to weak changes) than the organism of a healthy individual. That is why physicians have grounds to be especially alarmed about patients when the sun is restless. /131

Today the question of an astronomical medical service is being raised more often; more thought is being given toward having solar forecasts assist physicians in treating patients and in preventing various complications.

There are many major and vital tasks in heliobiology. They are not limited only to observations at the surface of the earth. The higher man ascends above the earth, the more he is deprived of the protection of the atmosphere shielding him against dangerous solar radiation. Heliobiology is a science that will serve mankind on earth and above the earth and in the unbounded expanses of space.

# LIFE, GRAVITY, AND WEIGHTLESSNESS



P. A. Korzhuyev, Doctor of Biological Sciences

Life, gravity, and weightlessness....what can there be in common in a combination of so dissimilar concepts that characterize the world of the living and the inanimate? Let us try to answer this by starting from two principles, mainly that an organism and his environment are an inseparable unity and that gravity forces have different effects on animals depending on whether the animals are in a water environment or on land.

Life on land differs from life in water in particular in that the action of gravity forces is stronger on land. The first emigrants onto land among the vertebrates encountered one of the most serious difficulties. To secure food for themselves or to save themselves from unfavorable conditions, it was impossible for them to move about, and in land conditions this meant overcoming the sharply growing action of gravity forces to which they were entirely unadapted, for in water an organism is nearly entirely free of gravity force and it is a condition close to weightlessness.

The transition to the different gravity field was accompanied by fundamental changes not only in the organism's structure but also in its functions, and with this -- his energetics. The first to give a proper evaluation of gravity's role in the life of an organism was K. E. Tsiolkovskiy as early as 1882. In an article, "Biology of Dwarfs and Giants," examining the relationship between the dimensions of organisms and the planet on which these organisms live, K. E. Tsiolkovskiy wrote: "If gravity force on our planet were different -- then the size of the most advanced people, just as all other creatures, would be different. For example, if gravity were to be reduced by a factor of 6 (as on the moon), human growth could rise by six times, mass by 216 times, and muscular strength by 35 times; the brain would also correspondingly increase. Such a person owing to the strength of his muscles (and his enlarged mind) would be the victor in spite of the fact that in the struggle with inanimate nature small people would have greater physical advantages."

Much later statements were made by some biologists on the fact that the form of animals, with a few exceptions involving aquatic animals, is due entirely to the force of earth gravity, that gravity force influences all bodies; and that anything at all related in the plant and animal kingdoms with the concept of ventral and dorsal sides, right or left side, bears the impress of gravity force reflected in the structure of an organism. An expression similar to the earlier statement made by K. E. Tsiolkovskiy was advanced in 1917 by Thomson, who stated that animal dimensions depend on the dimensions of our planet and in the event that gravity forces doubled, most land species would be similar to short-legged fossil reptiles, and if gravity force were reduced by half, conversely, they would become light, delicate, more active, but requiring less energy. /134

In 1960 our compatriot B. Ya.Brovar attempted to find a relationship between gravity force and the structure of an organism, by studying agricultural animals. He emphasized that these questions "are of considerable novelty, and therefore compared with some usual biological concepts, they are somewhat strange, while in other respects they are vague...." All these expressions show that gravity is a factor of enormous import, whether thus far outside the purview of biologists. Doubtless, gravity force is one of the most powerful factors governing the evolution of life on our planet, and discovering the principles of the evolution of organisms is impossible if we ignore the role of gravity.

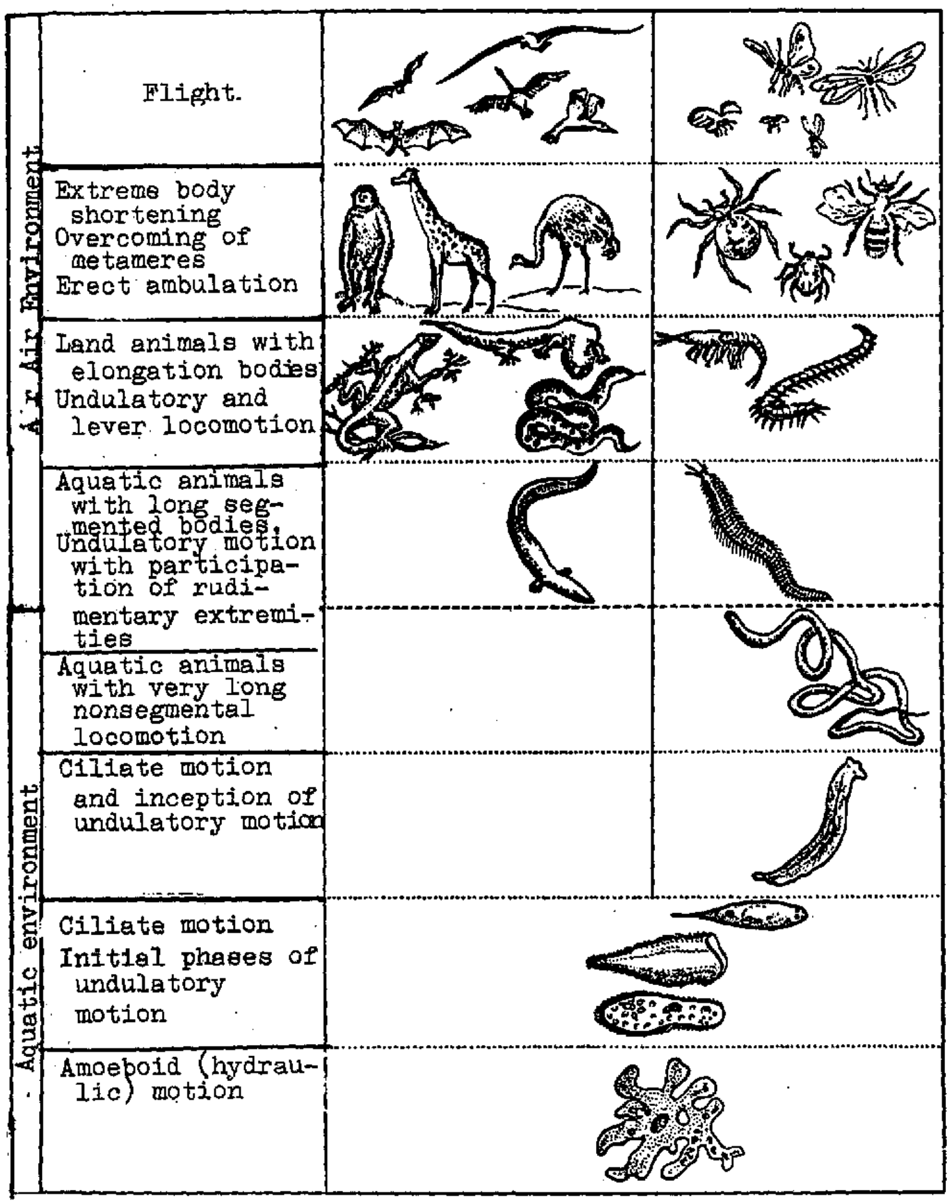
Gravity's role could have been brought to light very simply if we were in a position to produce conditions of prolonged weightlessness on earth. Thus far this does not appear possible and therefore the nature of the influence of gravity on animal and human organisms remains unclear.

Since, however, the surface of our planet is covered with a watery envelope only to three-fourths of its area, while one-fourth represents land and since organisms inhabit both water and land, we have the possibility of finding out the role of gravity force in the light of these two animal groups.

At the present time this is likely the only possibility of determining the role of gravity in the evolution of life on earth.

Scientific data on the biology of various groups of vertebrate animals even today suggests the conclusion that the evolution of land invertebrate animals is basically the <u>evolution of adaptations oriented at overcoming the force of gravity</u>.

Thus far biologists have ignored this aspect of research, being interested mainly in the effect of factors like temperature, light, moisture, etc., which doubtless are vital in characterizing the biology of animal groups studied. However, without clarifying gravity's role we cannot fully evaluate even the role of other factors, for animal behavior in large part is determined by how fully an animal overcomes the force of gravity. This degree of success determines the specific level of energetics, and thus the




Scheme of phylogenetic evolution of body form, segmentation, and principal modes of movement among animals (after L. A. Zenkevich). /135 rate of respiration and nutrition. More concisely, an animal's entire behavior is to a large extent determined by how advanced are its mechanisms for overcoming gravity.

To appraise the state of advancement of the mechanisms for overcoming gravity in various representatives of land and aquatic animals, we present a scheme from a fundamental work by L. A. Zenkevich, Corresponding Member of the USSR Academy of Sciences, Ocherki po Evolyutsii Dvigatel'nogo Apparata Zhivotnykh /Essays on the Evolution of the Motor Apparatus of Animals/ (1944); in this book the modes of locomotion of various groups of existing animals are compared. This scheme shows in very graphic form the evolution of modes of locomotion of animals over a broad phylogenetic plane.

L. A. Zenkevich distinguishes four main modes of animal locomotion: amoeboid (hydraulic) ciliate (or flagellate), wave-like bending of a body or its extreme lobes (or membranes), and locomotion using extremities. There is also the jet type of locomotion, however, it has limited distribution. /136

Locomotion by means of wave-like bending of a body or its extreme lobes (or membranes) is found in protozoans, and of the multicellular animals -- in numerous worms and certain arthropods, in molluscans, fish, amphibians, reptiles, and aquatic mammals. The stepping mode of locomotion is characteristic of certain rhizopods and Infusoria, certain coelenterates, Tubelaria, Rotifera, leeches, and echinoderms, not to speak of arthropods and vertebrate animals.

With regard to the latter, among land representatives of vertebrates extremities have been extensively developed, comprising a complicated system of levers providing for extremely high speeds of locomotion. Incidentally, not only does the system of extremities, but the entire organism participate in providing high speeds of locomotion.

It must be noted that the first emigrants onto dry land -- the amphibians -- still had weak extremities. In the literal sense, the animals crawl on their bellies while their body retains the shape typical of fish. In contrast, the higher representatives of vertebrate animals, already overcoming gravity to perfection, have a complicated system of levers in the form of extremities and a greatly shortened trunk.

In the aquatic environment where gravity is severely weakened, fairly simple adaptations to provide animal locomotion suffice. In land conditions this requires extremely strong structures in the form of a complex system of levers and a very decided change in body shape -- its shortening, or "abbreviation". Doubtless, this evolution in structures for organism locomotion in land conditions has enormous adaptive significance both for acquiring food as well as for protection against unfavorable conditions.

TABLE 1. MODES OF LOCOMOTION FOR CERTAIN ANIMALS

| Animal | Medium | Speed, $\frac{km}{hr}$ | Animal | Medium | Speed, $\frac{km}{hr}$ |
|---|---|---|---|---|---|
| Swift | Air | Above 100 | Cheetah | Land | Above 100 |
| Dragonfly | " | To 95 | Saiga | " | To 75 |
| Swordfish | Water | Above 100 | Horse | " | To 60 |
| Porpoise | " | Above 70 | Tortoise | " | To 0.4 |

Data on the speeds of locomotion of certain representatives of land and aquatic animals are of interest. Noteworthy is the fact that in all three environments -- aquatic, air, and land -- the maximum speed of locomotion is roughly of the same order, about 100 km per hour (Table 1). Unquestionably, the roughly identical maximum speeds in the three different environments -- -- water, air, and on land -- are achieved at the cost of different forces, different energy outputs, and therefore, for example, in an air and an aquatic environment animals can travel at top speeds for long periods of time, while on land conditions, an animal can achieve these high speeds only for a very short time, of several minutes. Strong fliers, like the swifts, or fast-moving fish like the tuna, mackerel, etc. are in motion for many hours, while the fastest moving land animal, the cheetah, is capable of high speeds only for several minutes. /137

What then are the morpho-functional mechanisms that enable animals to achieve locomotion at top speeds in different environments -- aquatic, land, or air? If we are concerned with vertebrate animals, then among the other patients oriented at overcoming the force of gravity, fundamental importance belongs to a skeleton providing not only mechanical strength, but also the level of the organism's energy outlays. Thus far morphologists have viewed the skeleton mainly as a framework governing the shape of an organism, and as a system of levers for animal locomotion. Here attention has been directed at the appearance of cavities in tubular bones as the principal condition of bone strength. In other words, the skeleton is regarded only as a mechanical system providing the support-protective-motor function of an organism. However, the notion of the skeleton only as a mechanical system is one-sided, therefore does not correspond to its actual biological importance.

In the same way, the idea of marrow as an independent organ has long retarded study of the biological causes responsible for the appearance of marrow and governing its entrenchment over the course of evolution. These reasons became clear only after a comparative study not only of qualitative, but also of quantitative features of the skeletons of various representatives of vertebrate animals. Comparative data on the quantitative characteristics of the skeletons of various representatives of vertebrate animals show that during the course of evolution the relative weight of the skeleton increased (Table 2).

TABLE 2. MEAN WEIGHT OF SKELETON, AND AMOUNTS OF BLOOD AND HEMOGLOBIN IN THE ORGANISM OF VARIOUS GROUPS OF VERTEBRATE ANIMALS.

| Animal | Nr. of spec. | Skeleton, % | Blood, % | Hemo-globin, g/kg | Animal | Nr. of spec. | Skeleton, % | Blood, % | Hemo-globin, g/kg |
|---|---|---|---|---|---|---|---|---|---|
| Chondrostei | 3 | 7,0 | 2,0–4,0 | 0,7–1,5 | Reptilia | 5 | 14,0 | 5,8 | 3,8 |
| Teleost. | 8 | 8,5 | 2,9 | 1,8 | Birds | 6 | 14,3 | 9,7 | 10,2 |
| Amphibians | 4 | 11,4 | 5,6 | 3,6 | Mammals | 18 | 14,2 | 7,3 | 12,1 |

The lightest skeleton is found in the Cyclostomata, Chondrostei, and teleost fishes. A considerable increase in relative skeletal weight is observed in the amphibians, while the heaviest skeletons are found in the birds and mammals. /138

One of the most essential features of the skeleton in the evolution of vertebrate animals must be regarded as the appearance of marrow in the transition from the aquatic to the land mode of life. Usually it is observed that marrow appeared only in tailless amphibians. Actually, marrow appeared at the time when the first invertebrate representatives emerged onto land. Marrow gained intense development in vertebrate animals already adapted to the land mode of life (reptiles and especially birds and mammals).

On the other hand, the skeletons of fishes lack marrow. On this grounds we believe that marrow is the achievement of land vertebrate animals. Only with the transition to the land mode of life did marrow appear. Its appearance evidently must be viewed as one of the main forms of adaptation to the land mode of life.

We maintain that hemopoiesis is a function not of marrow, but is a function of the skeleton. For only from this viewpoint do the causes responsible for the appearance of marrow and its development in various groups of vertebrate animals become understandable.

In fishes as primarily aquatic animals organs of hemopoiesis include the spleen, kidneys, and intestinal walls. In the first emigrants onto land among the vertebrate animals -- amphibians -- beside the spleen, the liver and the skeleton are organs of hemopoiesis. Therefore, with the emergence onto land, the skeleton took on a new function. Subsequently, in the mastery of land this skeletal function gained very great development. This fact meant that the relative weight of the skeleton increased appreciably, in some cases amounting to more than 20 percent of total body weight, while it averages upwards of 14 percent of body weight for mammals and birds.

Remarkably, the excess over the relative skeletal weight of /139 fishes of more than twofold, and in some cases even threefold in many representatives of mammals and birds is achieved not by increasing the weight of the compact matter providing the mechanical strength of the skeleton, but due to marrow. For example, in the reindeer, an excellent runner, the relative weight of marrow compared to skeletal weight is more than 45 percent, while in a newborn reindeer foal -- about 60 percent of skeletal weight. This means that nearly half the skeletal weight of land mammals is accounted for by marrow. In this respect, birds occupy a somewhat special position, evidently owing to their ability to fly. We know that in many representatives of the birds most of the tubular bones exhibit pneumaticity, which is grounds for concluding that the reduced weight of the avian skeleton is a necessary condition for flight.

All this shows the extremely vital role of marrow in the life of land vertebrate animals and especially of their higher representatives -- birds and mammals. In this regard, data on the weight of the hemopoietic organs of birds as the primarily air animals and of mammals as land animals may be of special interest. While the weight of the spleen and kidneys in fishes serving the function of hemopoiesis represents only tenths of a percent of body weight, in mammals marrow weight is 7.0 percent of body weight.

These differences in the relative weights of hemopoietic organs that serve primarily as organs for the synthesis of hemoglobin point to the fact that among land vertebrate animals, especially in fast-traveling or high-traveling animals, that is, animals easily overcoming the force of gravity, there are powerful mechanisms with which the force of gravity is overcome, for the relatively high weight of the foci of hemoglobin synthesis is the basic condition for the uninterrupted supply of oxygen to the functioning organs of an animal. The more active an animal, the more greatly ramified is the focus of hemoglobin synthesis, the more hemoglobin is supplied into the animal's blood, the more oxygen is transported to the cells and tissues of the animal's body, and the more easily it overcomes gravity. /140

If there is validity to the principle that the relative skeletal weight, and thus of its most important components -- marrow -- depends on the perfection with which the animal organism overcomes gravity, then we can expect that the existence of an animal in conditions with a different, weakened, gravity field, for example, in water, must lead to a decrease (a "lightening")of the skeleton and marrow, for in this case less force is needed to overcome gravity. In particular, secondarily-aquatic mammals such as cetaceans and pinnipeds must have relatively lighter skeletons and less marrow compared with land mammals.

Data we assembled on the characteristics of the relative weight of the skeleton and marrow in porpoises and seals show that the skeletal weight of the seal and the porpoise is roughly one-half that for land mammals.

Available data afford grounds for the conclusion that the force of gravity is a powerful factor governing the evolution of aquatic and land vertebrate animals.

The normal activity of marrow in man and animals occurs in a gravity field of specific intensity. Elimination of this factor over long periods of time must disturb the existing relationships between marrow and other systems of the organism. So we must give thought to preventive measures guarding against the possibility of undesirable consequences for astronauts, since prolonged weightlessness evidently is by no means the harmless factor to which one can become adapted.

The enormous arsenal of facts which biology now has available indicates that replacing the environmental habitat always brings about a restructuring of an organism in some direction. On the other hand, if we can imagine that there were only dry land on our planet, or that the entire surface of the planet were covered with water, that is, that life proceeded in a single gravity field, our planet would probably not have the diversity of organisms, and the character of biological evolution would have taken an altogether different direction.

Only changes in environmental characteristics represent the primary cause that determines changes in the nature of an organism, his structure, and functions. Essentially in this lies the greatest significance of the principle that the organism and its environment are a unity, since the organism cannot remain indifferent to changes in the main components of his environment.

The fact that weightlessness is a phenomenon that at the very least is not without consequences can be seen even from the results of the long flight (from 14 to 21 days) of the American astronauts and experimental dogs Ugolek and Veterok, in whom increased excretion of calcium from the organism was found, that is, the most important skeletal constituent. If the decalcification continued for /141
a long enough time, the functioning of marrow would be disturbed. Moreover, we know, for example, that in ricketts associated with the disturbance of calcium metabolism, there is strongly pronounced anemia in man and animals.

Naturally, future studies will show how valid are the fears expressed here, however, data, even though very limited at present, quite definitely indicate that prolonged weightlessness is a phenomenon to which the greatest caution must be shown, and there is no ground for recording it as a factor, that is absolutely innocuous.

Another aspect of the problem of prolonged weightlessness is of interest from the general biological point of view. In fact, prolonged weightlessness is a factor which the inhabitants of our planet, both man and animals, will encounter for the first time, when they fly to other planets or to the stars. Therefore, they will have no experience in this respect. The complexity of the problem lies in the fact that the transition to the state of weightlessness will be very abrupt; the organism must adapt at once to new conditions. We know, for example, that the transition of vertebrate animals from the aquatic to the land mode of life was quite lengthy, involved with fundamental changes in the nature of the organism. And finally, these changes were in some way reflected in the hereditary nature of the organism or, as is now customarily phrased, were coded in the chromosomes as the material carriers of heredity.

But in the event of the transition to prolonged weightlessness, there will be no coding, for organisms will encounter this phenomenon for the first time in the entire history of life on our planet, several billions of years.

Therefore, the appearance of fundamentally new conditions in the form of prolonged weightlessness demanding adaptive changes on a large scale in the animal organism compels biologists to deal with the thesis of the important role of the environment in the light of an organism, on the formative influence of the environment, as occurred when the first land vertebrate animals appeared.

The situation of prolonged weightlessness is another illustration of the principle that the coding of hereditary properties cannot ensure necessary forms of animal behavior in changing environmental conditions, for the animal organism must solve each time anew the problems confronting it. It is precisely the recognition of the principle that the organism and its environment are a unity that makes it possible to foresee with high probability the response of the organism of animals and man to fundamentally new conditions of prolonged weightlessness. Therefore one of the main goals in space biology is to develop ahead of time a complex of measures preventing the possible occurrence of harmful consequences to animal and human organisms resulting from prolonged residence in conditions of weightlessness.

# THE SUN -- AS A FRIEND /138

N. V. Pushkov, Doctor of Physico-Mathematical Sciences

The multiplication of locusts, the beet pest, rodents, and other agricultural pests is related to cycles of solar activity. Some researchers claim that human blood reacts to solar flares. In one respectable German magazine it has been reported that magnetic phenomena are associated with the number of suicides and accidents. Italian chemist Giorgio Piccardi claims that the sedimentation rate of fine suspended particles in colloidal solutions is also associated with solar activity. A list of these investigations and claims can be extended. And in our country biologists and physicians and entire scientific research organizations are engaged in research on the effect solar activity has on human functioning.

But I wish to say one thing in this respect: scientists are still very far from unanimous on this problem. More lengthy series of observations and experiments are needed. And my profound conviction is that any categorical assertion that solar activity affects human life can only stir unnecessary agitation and discredit the very idea of research. Let us gather patience....besides, /139 scientists usually omit one detail in their discussions about the harm of solar radiation. Namely this, that our civilization with its enormous electronic industry, powerful radio networks, and industrial complexes produces the same kind of radiation as the solar type that reaches us, but in a much more intense form. Industrial centers are enveloped in magnetic fields of radiation at an intensity compared with the "work" of the sun is negligible. And man as you can see does not especially suffer from this. But if the problem "radiation and man" is still studied from the biological standpoint, we must begin precisely from this aspect.

In my view, solar activity does not pose any hazard to us. And ultimately we are all children of the sun. We live and develop owing to the sun and, if every 11 years our star supposedly sent a "charge of death" to earth, mankind would long since have been wiped out. But actually we observed quite the opposite: the vigorous growth in the earth's population. Thus, we have all reason to be confident that: our sun is a powerful and good friend of mankind.

# THE COSMOS IN A DROP OF WATER /142

G. Piccardi, professor (Italy)

There are closed systems and open systems in the world. Closed systems usually are relatively simple and therefore are easily described. Experimental conditions depend only on the operator. They are not numerous, all is known and easily regulated. Results obtained when working with these systems are reproducible.

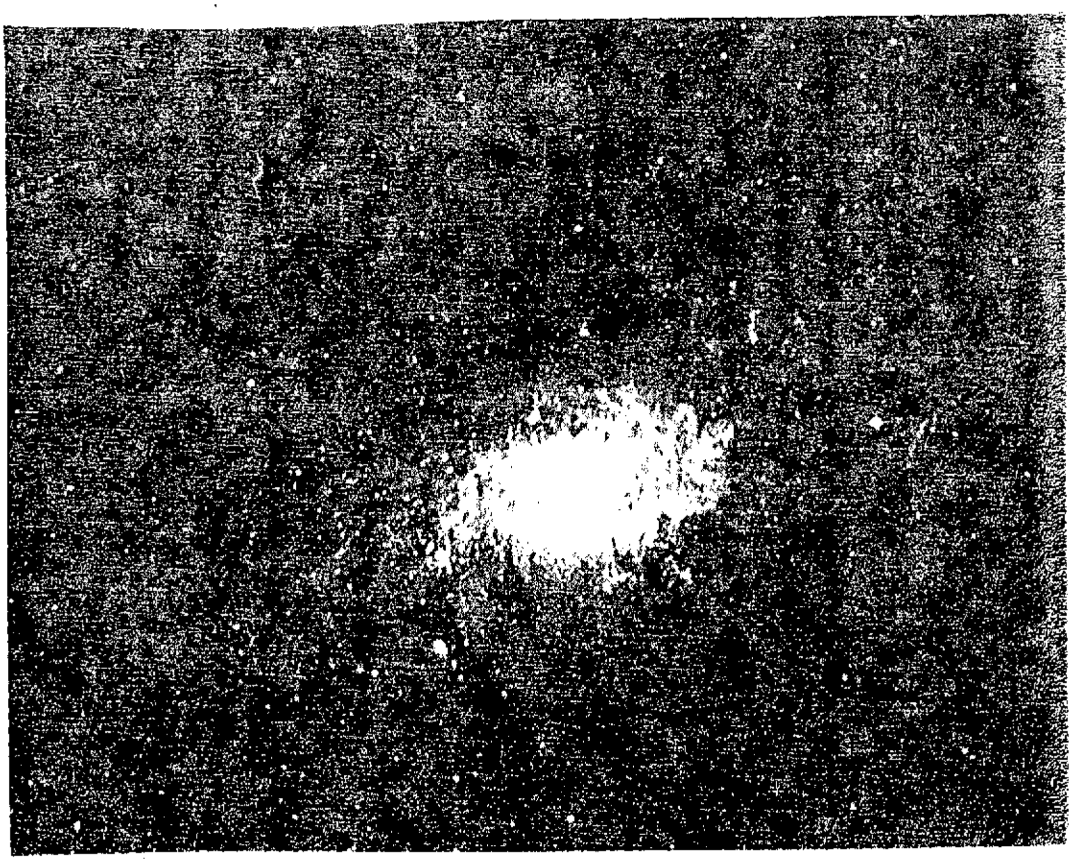
But open systems, in contrast, are extremely complicated and therefore are described only with difficulty. They appear to be infinitely unstable. The slightest perturbation can modify them, and this variability is infinitely great. They are sensitive to not only the variables that the experimenter introduces into them, but also the variables acting from without. Results obtained when working with these systems in constant conditions prove to be inconstant and show fluctuations with time. Their nonreproducibility is due to the inconstancy of external conditions. Phenomena occurring in open systems are called fluctuations.

A very large part of phenomena are classified as fluctuating. Their particularly major importance is in the biological sciences.

A living organism cannot exist if it is not an open system interacting with forces filling the space in which it lives. To isolate or close it means to kill it. The laws of physics are complete, rigorous, and exact and they are implacable to such a sensitive and susceptible system. A living organism needs freedom; it must have the opportunity to change in a thousand different ways and to provide all kinds of responses to what occurs around it. But it must never reach the state of equilibrium, since equilibrium is death. It must oppose a spontaneous process carrying it irreversibly into the state of equilibrium. Any spontaneous change in the inorganic world, according to well-known laws, leads ultimately to equilibrium. For living organisms these laws mean a death sentence. But living organisms oppose these laws and block the attainment of equilibrium, by taking from without, from the environment, the energy they need in order to keep themselves as far as possible from the equilibrium state. Therefore we can easily understand why biological systems are always open -- -- all without exception.

Powerful physical forces annihilate life or disrupt it to the extent that it can respond only abnormally in our experiments. No mega-electron-volts, no thousands of amperes, no tens of thousands of magnetic units! Studying life in this way is of course nonsense! Life requires thousandths of a volt, microamperes, and magnetic fields in several hundred-thousandths of a unit. A toy magnet is more than adequate to produce substantial effects.

Life arises not at the atomic or molecular level, but at the level of higher organization. It is exercised at the level of open systems, intermediate phases, large liquid systems, colloids.



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Our galaxy. Possibly some processes occurring in earth organisms are associated with the motion of the sun and earth around the galactic core.

A single gram of a substance in the colloidal state sometimes has a surface of 1 $km^2$. Imagine that electrical charges are induced and disappear over this vast surface, liquid structures are built up, force fields are born and that all this at any moment of time can change under extremely weak, very light perturbation by even weak forces or very low frequencies.

Water is this "elixir of life." And it is thus called with good reason. Let us examine why. /144

Water exhibits extraordinary properties compared with those of other compounds of the same type. Its physical and physico-chemical behavior is altogether out of the normal. Water is the most puzzling of puzzling substances. Already thousands of studies have been written about water, but we are only at the threshhold of a genuine knowledge of it.

It is very difficult to experiment with water, since it has not only well-defined properties that can be understood by ordinary physical methods, but other properties, subtle, that slip from physical measurement. However, physician, biologists, hydrologists, and balneologists know well that these subtle properties exist and that they can be evaluated by the influence that water has on such sensitive systems as biological systems.

Kinds of water distilled in natural fashion, for example, rain water or melted snow, are not at all identical to each other. Water long preserves changes in its structure. Its structure can be modified, for example, by exposure to a weak electromagnetic field of very low frequency. This kind of water, investigated by generally accepted methods, shows no difference at all from ordinary water, but its manifestations are different. For example, boiler scale crystallizes in different fashion in a boiler fed with ordinary water, from the pattern in a boiler fed with water irradiated at low frequencies.

It is redundant to state that water is a liquid that continuously changes and preserves a "memory" of its history for quite a long time. It can be viewed as an open system, since exhibiting several structures, it ultimately is a heterogeneous system.

Cosmic forces affect water and its properties very strongly. After the first investigations by Lavoisier and Volta (end of the 18th to beginning of the 19th centuries), one must wait until 1935 in order to begin to puzzle out (together with Bernal and /145
Fowler) that the structure of water is variable and that its internal qualities ascribed it by biologists empirically and often without real proof can be quite authentic.

The chapter on water in the great book of sciences being written slowly and with much difficulty. It is extremely difficult to study this chapter. It is impossible to make advances in it if one does not consider that many effects occurring in water are classified as fluctuating. But this chapter is uncommon and fascinating, since it can bring us closer to understanding the riddle of life. Strangely enough, it proved easier to send a rocket to the moon than to determine the exact qualities of the liquid most widespread on earth. This gives us a grasp of how difficult our problem is.

Already in 1915, A. L. Chizhevskiy in Russia was investigating biological effects associated with cosmic variables, about which no one had given thought until then. At that time, just as in the age of Hippocratus, only meteorological factors were regarded as important variables. In his book published in 1935, Chizhevskiy presented a number of investigations and proposed a series of tests, urging scientists to unite their efforts to find out how biological effects are associated with physical phenomena in space. This work brought the scientist world renown. The last book by Chizhevskiy, Aeroionizatsiya /Aeroionization/ appeared in 1961. At the present time when the concept of fluctuating phenomena is near its triumph, it is a valuable source of new ideas.

The well-known Soviet hematologist N. Shul'ts made special clinical studies showing that there is a definite relationship between the leucocytic count in blood and the number of sunspots. Recently these leucocytic counts led to an even more astounding discovery, which we will relate below.

The author is a pioneer in another field. He studied numerous reactions of inorganic life that do not provide reproducible results, and after many unsuccessful attempts was able to show that this nonreproducibility depends on the operation of external /146 factors and that there is a definite connection between cosmic phenomena and chemical reactions. This took 16 years of work. But it was necessary to go even further. In 1951 he set up appropriate chemical tests and by using them began extensive investigations to determine precisely what cosmic effects influenced chemical reactions. He principally studied the rate of deposition in water of small standard amounts of certain bismuth compounds.

These studies were conducted in Florence continuously since 1951. Every day at the same hours special groups of coworkers providing for continuity of the investigation conducted the same experiments. Several hundreds of thousands of experiments were performed -- today there are daily records covering nearly 14 years.

Chemical tests were then begun in Brussels (1952), in Vienna (1953), and at many other points. During the International Geophysical Year, they were carried out in many locations of the Northern and Southern hemispheres.

Later, the National Center for Atmospheric Research in the United States and centers in several other countries began the chemical tests.

Concerning the external phenomena that can affect our tests, we have not formulated a theory and have not advanced hypotheses. The results of these studies have unexpectedly shown us what we wished to know.

What then did we see after such a long time of anticipation and so arduous efforts?

We saw a powerful king surrounded by an entire retinue. The king was solar activity and the retinue consisted of the phenomena produced by this activity on earth: perturbations in the atmosphere, magnetic storms, and electromagnetic waves of very great length (kilometers, tens, hundreds, thousands of kilometers), what today is designated by VLF (very low frequency) and ULF ( ultra low frequency).

The relationship between the reactions of the chemical tests and solar activity measured by Wolf numbers is extremely significant. Just as significant was the relationship between these reactions and solar flares, and also the relationship between these reactions with terrestrial magnetism and ionospheric perturbations. The effect of long waves can easily be traced in a laboratory by producing VLF waves artificially. All this occurred in 1955. At the present time it has been found possible to once again correct our chemical data. The relationships prove to be even more amazing than in 1955. This actually meant corroboration. /147

No other relationship between solar and terrestrial phenomena could be more authentic or more significant. The eloquence of the connection between solar activity and inorganic chemical reaction made it possible to give a new meaning to further-unclear relationships between biological phenomena and external cosmic factors.

When the chemical tests were investigated, something strange was noted. One of the chemical tests revealed a distinctive annual variability with a deep minimum occurring in spring. The characteristics of this variability compelled the researchers to think about a combination of circular motion with linear. In our case -- the circular motion of the earth and its orbit around the sun with the nearly linear motion of the sun toward the constellation Hercules. We thereupon had to ponder the spiral motion of the earth in our galaxy. This motion must have a physical influence on general conditions on earth regardless of the time of the year. According to this hypothesis advanced by the author in 1954, the effect of the earth's spiral motion must show up simultaneously in the Northern and the Southern hemispheres of our planet. This is the reason that compelled us to conduct experiments during the IGY period. Results of these experiments entirely supported our hypothesis.

If inorganic colloidal systems respond to major cosmic phenomena so explicitly, then how do biological systems, even more complex and sensitive respond to them? We can foresee that they respond in a similar fashion. This prediction was splendidly confirmed in experiments. A relationship between the number of sunspots and the leucocytic formula in blood that Shul'ts found was entirely the same as between the number of sunspots and the reactions of the chemical tests. The simultaneous carrying out of experiments in Italy, Germany, and Japan again confirmed that all tests, biological and nonbiological, reveal the same dynamics at the same time.

Chemical tests, following in regular fashion the number of sunspots, began to behave differently in 1958. Instead of increasing together with the number of sunspots, they began to decrease, and then increase when the number of sunspots began to decrease. This was unexplainable. Shul'ts wrote the author, relating that the leucocytic count in blood revealed the same abnormal behavior. This means that the phenomenon was general. An explanation was obtained when Gnevyshev, the director of the High-Altitude Observatory in Kislovodsk, on checking data gathered from various areas around the world, showed that solar activity revealed a distinctive deviation from the normal in 1958. It /148
proved to be "two-horned" with two maxima, just like the behavior of the chemical tests and the leucocytic count.

Biology can now acquire a precision which it formerly did not have. The precision will be caused by the fact that fluctuation revealed by biological systems and the nonreproducibility of results are not flaws deserving regret and condemnation, but positive elements that enable us within the framework of existing methods to assign significance and rigor to the biological experiment. To do this, it is sufficient to relate the biological phenomena with the cosmic phenomena by means of a chemical test. The chemical test gives the reference point from which the results of the biological experiment can be linked.

The time has come to reason in the language of broad generalities even in the case of very local and very modest phenomena. Then we will find everywhere, especially in living organisms, the presence of the cosmos.

# WATER AND THE MAGNET /144

V. Klassen, Doctor of Technical Sciences,
and
V. Minenko, Candidate of Chemical Sciences

Along with the worship of the sun in ancient peoples, there was the worship of water. Our ancestors were knowing. All forms of life on earth are inconceivable without water. Even "the king of nature" -- man consists of two-thirds ordinary water. All the geological history of our planet is associated with the activity of water. Most modern technological processes comprising the core of industry must use water.

The properties of water have been studied in great detail. It turns out that here everything has been clarified and everything settled. But as sometimes occurs in science, observations "suddenly" appear that open a new chapter in our knowledge of water.

It began with small things. In the 1930's Soviet physicists R. Ya. Berlaga, F. K. Gorskiy, and others discovered that if supersaturated aqueous solution of salts are placed in a magnetic field, then the precipitation of crystals is appreciably modified. Italian scientist G. Piccardi observed that if a metal hood absorbing electromagnetic waves surrounding the earth is fitted over a vessel containing water, this markedly affects the rate at which the finest colloidal particles settle out in the water.

Later, staff members at the Khar'kov Engineering Economics Institute established that exposure, for several fractions of a second, of water to a relatively weak magnetic field changes nearly all its physicochemical properties: surface tension, viscosity, electroconductivity, and even density. It is amazing that water is able to preserve the changed properties for several days. /145

Attempts were made at a theoretical analysis of these astounding facts, but thus far no strict scientific explanation has been forthcoming.

Evidently, these puzzling phenomena are in some way associated with the change in the water's structure under the effect of a magnetic field. Its molecules connected to each other mainly by relatively weak, so-called hydrogen bonds, form complex variable aggregates. A definite ordering of these aggregates is observed in ice. Ordinary water has a loose open-work structure, that can be easily changed on exposure to external forces. It is difficult to imagine what deciphering this next mystery of nature will mean for mankind. But even today there is quite a number of incontrovertible data and observations allowing us to state that magnetic treatment of water, its unique "refinement" can be of enormous significance. /146

For example, it was found that magnetic treatment modifies the structure of salts deposited in steam boilers when water is heated. Instead of a hard layer of scale, a loose, easily removed powder is formed.

Preventing the formation of scale by passing water through alternating magnetic fields is now being used with great economic effect in many domestic enterprises. Moreover, it was found that after magnetic treatment water itself begins to dissolve the scale which had formed earlier.

There are data showing that "magnetized" water appreciably speeds plant growth. Or yet another example: by statistical analysis of an enormous (about 3.0 million) number of experiments, G. Piccardi established a definite relationship between solar activity, the properties of water, and human health. Evidently, fluctuations in the earth's magnetic field associated with solar activity are at work here.

# IN THE RAYS OF THE SUN

"The discovery of truth in the heavens, whatever the object of study, differs little from discovering a crime on earth. In one case the cause is sought for, and in the other -- -- the criminal, but the process of seeking is entirely identical."

P. Lowell

The statement that the sun is the source of life on earth has long become trivial. Can, however, a similar statement be extended to the other bodies in our solar system?

In the past century, some of the romantically inclined scientists populated not only Mars and Venus, but in general all bodies in the solar system, even the sun with rational creatures! This is a wholly unwarranted extreme position, contradicting modern data on the extremal conditions which restrict the life of protein organisms -- today's scientist has convincingly proven the unsoundness of these views. In our day sometimes we observe another extreme position. Some scientists regard the earth as the only habitat for life in the solar system. The main basis for these views is the absence of direct proof thus far that life exists outside the earth.

Still, indirect proofs that bodies of the solar system are populated with living organisms exist, they are considerable, and they show that truth lies somewhere between the two extreme points of view.

# EXOBIOLOGY: METHODS AND PROBLEMS /150

A. A. Imshenetskiy, Academician

Exobiology emerged quite recently as an independent discipline. Its birth was prepared for by advances in astronomy, mathematics, physics, chemistry, mechanics, and technology -- in other words, all the sciences that have made study of space realistic.

Four directions have already been outlined in studies underway in exobiology, or space biology.

The first of these is related to the study of the effect that outer space factors have on living creatures. This experimental ecological direction naturally did not emerge in a void; it derived from many years of experiment accumulating in ecology and biophysics.

The second direction is associated with the study of planets and meteorites from the standpoints of biology. It unites investigations conducted using physical methods capable of detecting, for example, absorption bands typical of chlorophyll; chemical and microbiological analyses of meteorites and cosmic dust are classified in this direction.

The third direction is the development of methods with which science is trying to detect life on planets and in space. Researers are studying "chemical evolution" in the universe and the possibility of the purely chemical synthesis of complex organic substances. The culminating stage in this development is the designing and building of automatic operating biological stations.

The first direction bears not as great a theoretical significance as the preceding directions, but is very important in actual practice. We are referring to preventing the carrying of earth forms of life to other planets. This led to the necessity of sterilizing spacecraft, which proved to be a much more complicated task than was assumed. In a relatively short time the limits of exobiology as a science and its relationship with space medicine have been clearly defined and a great deal of very interesting experimental material has been gathered.

## Microorganisms and Space

The main difficulty encountered by exobiology in studying the effect of space conditions on living creatures is the impossibility of producing the conditions of space in a laboratory. Thus, the vacuum existing is $10^{-16}$ mm Hg. But an experimenter on earth in the best of cases can achieve a vacuum of $10^{-10}$ mm or $10^{-11}$ mm Hg. By placing various organisms in this vacuum, it was possible to find that some nonsporogenic bacteria die in /151 these conditions, while the spores of bacteria, conodia, and mycelia of several fungi remain alive. In these same experiments another curious detail was also found: some species of bacteria left as a control in the laboratory died sooner than the same species in conditions of vacuum.

This kind of experiment allows us to state that a vacuum prevalent in space does not kill earth bacteria.

Of exceptional interest is the effect of ionizing radiation on microorganisms. Radiobiology firmly established that cosmic radiation can be dangerous to astronauts. Therefore a great deal of attention is being given to the problem of protecting astronauts from radiation damage, which becomes especially urgent during periods of solar flares. However, in contrast to this microorganisms are unusually resistant to ionizing radiation, and doses that are absolutely lethal for animals and man do not cause harm to microbes. Bacteria not succumbing from 2-3 million rads have been isolated from the water of atomic reactors. Therefore ionizing radiation does not kill those microbes floating in space -- there may not even be doses of this intensity in space. True, sometimes the assumption is made that the radioactive elements contained in a bacterial score, for example, potassium, can become a source of secondary radiation, which ultimately kills the cell. Though this is possible, a very long time is needed for this process.

We observe an entirely different picture when we encounter the effect of ultraviolet rays in space. The absence of the screen of dust, clouds, and ozones shielding the earth against ultraviolet rays and the very high doses make these rays in space absolutely lethal for all microorganisms without exception.

And still it would be incorrect to assert that all microorganisms must necessarily be killed by ultraviolet rays. The point is that even very delicate films or the thinnest layer of compact substances already entirely absorb these rays and reliably protect cells against their action. Here is an example: if the cells of microbes are on a polished steel plate, then when irradiated with ultraviolet rays they die rapidly. However, these same microbes, but now placed on the surface of a slightly rusted steel plate remain alive after an ultraviolet dose of $2.9 \cdot 10^{12}$ erg/$cm^2$, a dose that is vastly higher than what they received in space in the course of a year. It is sufficient for any microbial cell to attach itself to a mineral dust speck in order to become insensitive to the action of ultraviolet rays.

We know that each year many tons of cosmic dust fall on the earth, therefore we are not correct in excluding the possibility of the shielding of microorganisms by this dust. This assumption was tested experimentally. Spores of the bacterium Bacillus cereus were coated with a film of chromium 800 A thick, and then even a high dose of ultraviolet ($7.8 \cdot 10^7$ erg/$cm^2$) proved to be impotent. A piece of the stony meteorite Kunashak was ground for the same purposes; spores of Bacillus megaterium were added to /152 the powder and using a binding agent micrometeorites of conical shape were prepared from the powder. The bacterial spores contained in the micrometeorites withstood a dose of ultraviolet rays of $7.8 \cdot 10^8$ erg/$cm^2$ without any harm.

All this shows that protection can be found very readily against a dose that is absolutely lethal to microbes, such as ultraviolet rays.

As for low temperatures, it has long since been found that the temperature of liquid air, liquid hydrogen, or liquid helium does not kill microorganisms. Therefore, the low temperatures prevalent in space have no harmful effect on bacteria.

Whereas 20-30 years ago it was believed that temperatures close to absolute zero could be withstood only by one-celled, relatively primitively organized creatures, today it has been shown that even higher plants, for example, black currant and certain insects are resistant to these temperatures (this of course does not mean that cooling this intense has no effect on metabolism, the structure of enzymatic proteins, etc.).

In speaking about the effect of space conditions on biological materials, we must state that usually the effect of individual space factors is studied. However, there are chambers simulating all conditions in space; in them test materials undergo simultaneous exposure to both low temperatures, vacuum, and various kinds of radiation. Of course, there is another procedural possibility, namely to send aloft in a rocket a small stand containing microbes to considerable altitudes. True, the exposure here is relatively brief, but nonetheless this method has been tested. Microorganisms sent into space via rocket did not die.

## "Artificial Planets"

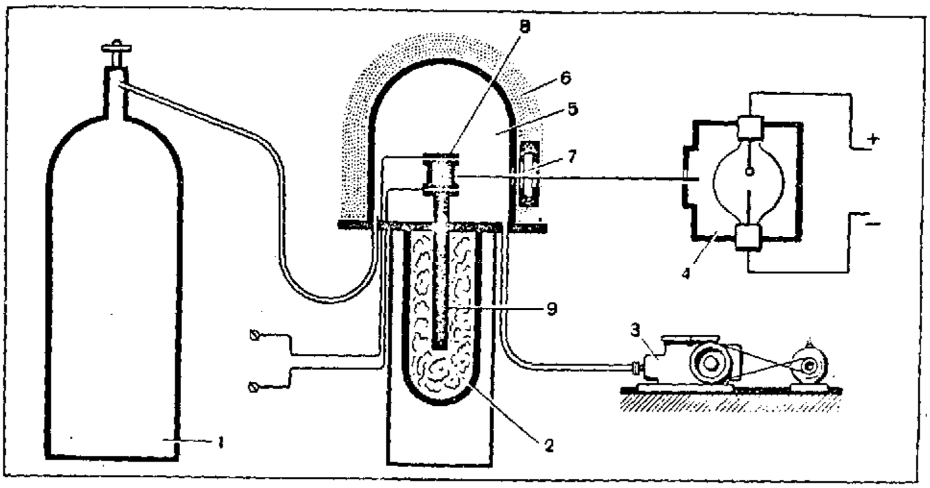
However painstaking are the experiments revealing the effect of individual space factors on living creatures, they necessarily must be continued using instruments reproducing the climate and conditions of life on a given planet. The behavior of microorganisms placed in an artificial Martian climate station has been studied most fully. However, we must add the qualification that the Martian climate is produced which, in the view of planetologists, exists on this planet. It is altogether probable that automatic stations landing on Mars will introduce corrections into these data.

The "artificial Mars" chamber built and functioning in the Institute of Microbiology, USSR Academy of Sciences, is a metal cabinet in which a small chamber under a hood with a quartz glass window is placed. The chamber is secured to a copper rod, and by cooling or heating the rod the chamber temperature is varied. "Artificial Mars" has a programming device that varies the temperature and regulates the operation of the entire installation. The following conditions are maintained in the chamber: the temperature is +25° C for 12 hours 15 minutes, and -60° C for an equal length of time; this corresponds to the diurnal fluctuations in temperature on Mars; the pressure is 7 mm Hg; the gas composition is 30 percent $CO_2$ and 70 percent $N_2$; this mixture does not contain water vapor; the chamber is irradiated with an ultraviolet lamp, and the intensity of this irradiation corresponds to the level which evidently exists on Mars.

Various microorganisms were placed in the chamber, and it soon became clear that ultraviolet rays gradually killed all the test cultures, including sporogenous species, yeasts, and mold fungi. Interestingly, so-called pigmented forms of bacteria, that is, those whose cells contained red, orange, or black pigments, were more resistant to the rays.

But the effect of the other two factors (temperature fluctuations and atmospheric composition) were not destructive. Later, the chamber was no longer irradiated with ultraviolet rays, since it was found that it is sufficient for the microbes to be buried several milimeters into soil in order to be entirely protected against ultraviolet rays.

In order to bring experimental conditions as close as possible to Martian conditions, the microorganisms were placed in a ground mineral, limonite -- it was assumed that the surface of Mars is covered with this mineral. By varying the moisture content, it was possible to show that some soil microbes can develop in the ground limonite (to which 2 percent garden soil was added) in cases when its moisture content was 3.8 percent, that is, equal

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Layout of "Artificial Mars" Chamber
1 -- cylinder containing gas mixture
2 -- vessel containing cooled mixture
3 -- pump
4 -- lamp producing ultraviolet rays
5 -- chamber for test material
6 -- heat-insulated chamber
7 -- "window" of quartz glass
8 -- heating element
9 -- copper rod

to the maximum hygroscopic moisture content. And this means that xerophytic microbes could propagate in Martian conditions. /154 There is every reason to assume that neither the lack of oxygen nor temperature fluctuations on Mars can limit the life of microorganisms. The restraining factors there can be the inadequate amount of water and soil and the ground. It is precisely for this reason that the conditions in which microbial life in the desert exists are closest to Martian. Hence we recognize the interest that exobiologists have shown in the microflora of desert soils. Expeditions were organized to the Karakumy, and to a desert in South America, where the distribution of microbes along the vertical was studied, as well as physiological characteristics and the systematic ranking of the species found.

It can be regarded as firmly established that some microbial cultures not only do not die in the conditions of "Artificial Mars", but are capable, as was shown, of propagating, even though slowly. It is interesting that during this work it was shown that our former ideas on the limits to the absolute moisture content of soil admitting microbial life were inexact. Xerophytic forms of microorganisms can reproduce even at a lower moisture content than was earlier assumed. This is one example how the study of space conditions enriches earth biology with new data.

## "Export" and "Import" of Life

It has long been known that intense storms and typhoons can sweep insects and even animals from the ground and carry them over considerable distances. This usually ends with a shower of caterpillars or other living creatures and at times caused superstitious dread.

It is quite obvious that strong gusts of wind are capable of lifting dust particles, and with them cells of microorganisms to very great heights. But can microscopic living creatures "take off" from the earth and be swept into the expanses of space? /145
Could earth microorganisms exist there?

Some scientists maintain that the pressure of light is quite adequate to carry off the most minute living creatures beyond the earth's gravity and to transport them into space. However, this hypothesis is improbable. The size and weight of microbial cells, even though small, still exceed the weight of the particles that light can carry into space. Therefore, the spontaneous "export" of earth forms of life is unrealistic. But the "export" of earth microorganisms with spacecraft to other planets became entirely possible; it is precisely this possibility that brought about the need to sterilize these craft.

The problem of whether the "import" of life from space to earth is much more complicated. Many outstanding scientists in the past and present century regarded and currently regard this possibility as quite realistic. The theory of the famed Swedish physical chemist S. Arrhenius gained very wide acceptance. He suggested that germs of life (thermophilic bacteria) were transported to earth from other planets, in particular from Venus, when it was a minimum distance from the earth. This theory was criticized and has been classified as idealistic.

Still, there is nothing idealistic in the actual fact of the transport of life from one planet to another. If this will be shown, then no changes will occur in our concepts of the origin and development of life. Arrhenius' theory deserves criticism, but for entirely other considerations. Panspermia -- the transport of life from one planet to another -- in no way resolves the main problem: how did life arise in the universe? The idealistic heart of this theory is that by assuming life to be eternal, it does not even attempt to pose the question of how life appeared. Arrhenius' theory does not answer the question of how life arose on the planet from which the germs of life were carried to earth. It is precisely for this reason that it is one of the unscientific theories that assumes an act of creation performed by a higher creature.

Did material fall on earth whose cosmic origin is beyond doubt? Each year $3 \cdot 10^6$ tons of cosmic dust fall on the earth's surface. The presence of a nickel isotope in it demonstrates its cosmic origin, and this dust has been detected in the Arctic and Antarctic on the surface of ice fields and snow. This has enabled representatives of various specialties to investigate it. Thus far samples of cosmic dust (collected in such a way that they were not contaminated) have not undergone microbiological analysis.

However, meteorites, which just like cosmic dust are emissaries from space, have been investigated and various microorganisms have been detected in them. Can we assume on the basis of purely theoretical considerations that living microbes are present in meteorites? Weren't microorganisms subjected to such physical factors that are capable of destroying all of life?

As we know, a meteorite on falling into the denser layers of the atmosphere heats up strongly and begins to glow. True, the high temperatures occur only in the surface sections of the meteorite, while its central regions are not heated to temperatures capable of killing bacterial spores. The dimensions of average meteorites are sufficient in order to entirely protect living cells in the central region of meteorites from exposure to ionizing radiation and ultraviolet rays. Thus, microorganisms in a meteorite need not necessarily die during its flight.

However, the foregoing still does not mean that here we do not face other, more complicated problems. The first of these is the duration of and the antibiotic state in which microorganisms must exist. Could they for thousands and millions of years have preserved their viability? It is altogether obvious that we cannot accept any covert life, that is, retarded metabolism for periods this lengthy. If this were possible, then it would be only if the metabolism had been entirely halted, and the structures of vital importance were not broken down. /157

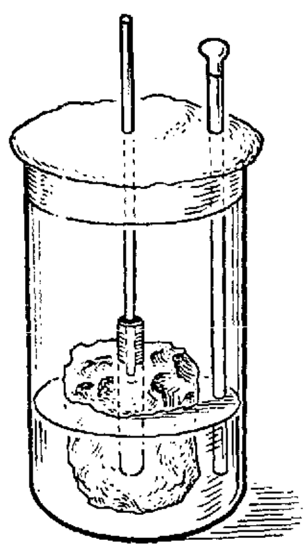
The fact that bacterial spores can preserve their viability for 150-200 years, has already been shown. But as for lengthier periods, here there are no experimental observations. Reports stating that rock salt, whose age is 250 million years, contains viable algae, were not confirmed after careful experimental testing both in our country as well as abroad. Therefore, this problem remains open in science. Some indirect arguments (the "aging" of protein, the absence of absolutely hermetic cell membranes, etc.) render this anabiosis improbable.

A second objection that can be made to investigators detecting microbes in meteorites is that the very process of the inception of meteorites occurs in conditions unfavorable for the existence of life on asteroids or other celestial bodies that serve as the origin of meteorites.

Development of a method for the microbiological analyses of meteorites was begun in the Institute of Microbiology, USSR Academy of Sciences.

A metal box with glass windows was designed and built for this purpose; a drilling unit is placed within the box. Rubber gloves for the experimenter's hands were built into the walls of the box. Before use, the box is placed in a large autoclave. Samples from pieces of rock and meteorites are collected in the box in sterile conditions and are implanted in a liquid nutrient medium.

First of all, we had to find out the following: are meteorites falling on earth suitable for microbiological analyses? Do they not become contaminated even after their fall by soil microflora? In order to answer this, we first carefully sterilized /158
pieces of rocks and meteorites, and we placed them in soil in different parts of our country. As the control we used sterile chunks stored in the laboratory. After different periods of time pieces of the samples were split in half in the sterile box and samples for analyses were taken from the central regions of the cleaved surface.



Experiment demonstrating the porosity of meteoritic material.

These experiments led to the following conclusions: 1) pieces of rock and meteorites lying on the surface of snow or ice in the Arctic are not contaminated by microorganisms in their central areas; 2) all samples near Moscow at the surface of soil became contaminated with soil microflora even after 4 days.

This means that meteorites falling in a field or in a forest are entirely unsuitable for microbiological analysis. Now it becomes understandable why so many diverse microorganisms were found in meteorites. These all were common forms that can easily be found in soil. Sterilization of the surfaces of meteorites provided no help at all, since microbes penetrated into the central sections of the meteorites. Porosity of meteorites can be proven with a simple experiment.

A channel is drilled into a meteorite, and into the channel a glass tube is inserted. The meteorite is half-buried in a nutrient medium poured into a large beaker sealed with a wad plug. The beaker is sterilized, and then through the tube in the drilled channel is introduced a liquid culture of blood prodigious bacteria, which on penetrating through the meteorite material, falls into the nutrient surrounding it, coloring it red.

Thus, the material of meteorites as a rule is porous and for this reason soil bacteria together with soil moisture penetrate within a meteorite that has fallen onto the earth.

## Chemical Evolution

The development of our ideas on extraterrestrial life and advances made in methods of detecting it have been strongly influenced by two directions in modern science. One is the advances in cosmochemistry, establishing that the same chemical elements and identical radicals can easily be detected in the universe. Of even greater significance was the fact that here in meteorites, specifically in carbonaceous chondrites, the most varied organic compounds were detected: amino acids, carbohydrates, hydrocarbons, purine and pyrimidine bases, the products of chlorophyll oxidation, etc. The assumption of secondary contamination of meteorites already on the earth by these compounds (just as in the case of bacteria) was entirely refuted. This assumption /159 of contamination is opposed by the high content of carbon in carbonaceous chondrites, amounting to three percent; and here we are speaking about carbon incorporated in the above-indicated organic compounds.

It is of course very tempting to suggest that all these compounds were synthesized at one time in space by living organisms and that subsequently the detection of these organic compounds indicates that life existed somewhere. However, this assumption is still on shaky ground. The conditions in which meteorites originated, as we have already said, are difficult to harmonize with the conditions in which life could have emerged and progressed. Therefore, all this diversity of organic compounds resulted from "chemical evolution," in other words, during the formation of complex compounds from the simplest compounds. This process occurred in cosmic conditions favorable for this purely chemical synthesis.

This point of view has been confirmed in studies by chemists engaged in synthesizing organic compounds. These efforts -- the results unquestionably must be classified as the most outstanding achievements of modern science; they demonstrated with exceptional cogency the possibility of the synthesis of various amino acids, carbohydrates, purine bases, lipids, and other compounds from such simple compounds as methane, carbon dioxide, hydrogen cyanide, and phosphates. Energy sources in this synthesis included the following: pressure, ultraviolet rays, ionizing radiation, or elevated temperatures, that is, namely the factors which did and still do exist in space and on the planets.

Thus, the origin of life on earth as well as in space was preceded by a prolonged period of chemical evolution, resulting in the emergence of diverse and quite complicated organic compounds. All this renders quite superfluous the oft-expressed earlier hypothesis that the pioneers of life were one-celled autotrophic creatures able to acquire energy by the oxidation of inorganic compounds and compositionally simple chemical compounds. The primary forms of life had varied organic sources of food and energy at their disposal, and these forms of course were not auto-, but heterotrophes.

Another extremely important conclusion which might be drawn based on the latest achievements in cosmic organochemistry and organic synthesis is the following: the appearance on other planets of complex organic compounds cannot yet serve as indisputable proof that life existed on these planets. Organic compounds can be detected on a planet, but by no means of biogenic origin. The reason for this is the chemical evolution which had gone on before.

Thus, it is quite indisputable that owing to the absence of an atmosphere, many more unchanged meteorites fell per unit surface of the moon (there is no atmosphere there) than on the earth's surface. Among these doubtless were carbonaceous chondrites containing organic compounds. The latter can be detected in chemical analyses of soil to be sent to the earth by automatic stations. And nontheless the detected organic matter cannot serve as proof that life existed on the moon. Moreover, a number of theoretical arguments allow us to maintain that the total disappearance of /160
life on the moon is vastly more probable than its presence. Still, we cannot categorically state this before experimental verification.

In this way chemical analyses of soil yielding valuable information about our planet still cannot answer the question as to whether life existed in given conditions.

## Methods of Detecting Extraterrestrial Life

But in this case what can serve as an indisputable criterion of the presence of life on a planet? The most convincing proof of this will of course be the growth and multiplication of living creatures. It is precisely for this reason when various methods of detecting life outside the earth are compared and evaluated, preference is given to the methods that permit establishing cell multiplication with reliability. And since microorganisms are the most widespread in nature, above all microorganisms must be sought for in efforts to find life outside the earth.

Microorganisms on other planets can be found in the ground, soil, or atmosphere. Therefore, a number of methods of taking samples for analyses are being developed. In one such instrument -- "Gulliver" -- an ingenious device has been suggested for taking samples for inoculation. Three small cylindrical charges are arranged along the periphery of the instrument. To each charge is attached a sticky silicone thread. The explosion of pyrotechnic cartridges expels the charges several meters away from the instrument. Then the silicone thread is wound up and, on being immersed in a nutrient medium, infects it with particles of soil sticking to it.

The multiplication of microorganisms in a nutrient medium can be established by using various automatic devices that simultaneously record the buildup in the turbidity of a medium, (nephelometry), pH change of the nutrient medium (potentiometry), and buildup in pressure in a vessel due to an evolving gas (manometry).

A very ingenious and precise method is based on adding to a nutrient medium organic compounds (carbohydrates, organic acids, and the like) containing labeled carbon. Multiplying microorganisms can decompose these compounds. And the amount of radioactive carbon evolved as carbon dioxide is determined with a miniature counter attached to the instrument. If the nutrient medium contains various compounds bearing labeled carbon (for example, glucose and protein), then by the amount of evolved carbon dioxide we can reach a rough idea of the physiology of the multiplying microorganisms.

The more diverse methods are used in elucidating metabolism in multiplying microorganisms, the more chances there are of acquiring reliable information, since some methods can give erroneous data. For example, the nutrient medium can become cloudy from dust falling into it.

When microorganism cells multiply, the intensity of all indicators recorded and relayed to earth steadily rises. The dynamics of all these processes is well known, and it is a reliable criterion of the true growth and multiplication of cells. Finally, there can be two containers with nutrient media onboard the automatic station. And as soon as an increase in changes begins in them, a strong-acting poisonous substance is added automatically to one of them, halting growth entirely. A continuing change in indicators in the other container will be reliable proof of the biogenic nature of the processes observed. /161

The instruments designed must not be overly sensitive, since the prospect of "discovering" life where it does not exist is very undesirable. On the other hand, the instrument must not give a negative answer if life actually exists on the planet explored. It is precisely for this reason that the reliability and sensitivity of proposed equipment are being vigorously discussed.

Though the multiplication of microorganisms is the sole indisputable sign of life, this does not mean that there are not other procedures that enable us to acquire valuable information. Thus, since the time of Louis Pasteur, optical activity has been regarded as one of the characteristics of life, and the "Pasteur probe" proposed for space research consists of a polarimeter, which must determine the optical activity in samples taken. Some dyes on combining with organic compounds produce complexes, readily detected, since they have the ability absorb waves at a strictly specific wave length. One proposed method is based on using a mass-spectrometer, which establishes the turnover of the oxygen isotope ($O^{18}$) occurring on exposure to microbial enzymes in compounds such as sulphates, nitrates, or phosphates. The uses of luminescence are quite varied. It can be used not only to find enzymatic activity, but when certain phosphors are employed, the luminescence of DNA contained in bacterial cells is possible.

The next stage in the investigations is to use a portable microscope fitted with a searching unit capable of finding individual cells in the field of view. Special devices will transmit visible microscopic pictures to earth. Here it is convenient to note that the task of exobiology includes the detection not only of life existing now, but also paleobiological studies. An automatic biological laboratory must be able to detect possible traces of former life. In terms of methods, this task will be made much easier by using microscopes providing several magnifications.

The question of the possible existence of forms of life simpler than microorganisms is the most complex and very difficult problem, from the standpoint of technique. And actually, these discoveries will probably give much greater interest in solving the problem of the origin of life than detecting such relatively complexly organized living creatures as microorganisms.

Another problem we have not yet looked at still remains. Can life on other planets be "built on other foundations" than earth life? There are a fair number of interesting hypotheses which admit of the possibility of life constructed not on a carbon, but on a silicon or germanium foundation. Compounds not of phosphorus, but sulfur will serve as sources of stored energy. Finally, it is not water, but compounds like glycols, ammonia, and others that figure as the solvent in organisms. It would be /162 unwarranted to classify all these hypotheses as antiscientific, but we have no grounds to reject earth concepts of extraterrestrial life. We must prepare to seek for life outside the earth, above all, by starting from the experience of the study of earth life. Only if all attempts to detect life on a carbon basis proves unsuccessful can efforts to find it in other directions be begun. This is the only possible solution to the problem at the present time.

As to method, exobiology is a more difficult situation than disciplines studying planets from other points of view. These disciplines are able to study planets at distances using various physical methods and to put very valuable information on planetary properties. Thus far there are no methods that would enable information about extraterrestrial life to be obtained in similar fashion. For this purpose, an automatically operating biological station must be at the surface of a planet. We are approaching this possibility. And it is difficult to overestimate the significance of the data which we will then obtain.



C-3

# MARS AND EARTH /154

L. Lozina-Lozinskiy, Doctor of Biological Sciences

In terms of method, simulating Martian and other conditions in closed chambers is imperfect, since due to the vital activity of organisms, the gas composition in them changes, traces of oxygen so vital to life disappear, and toxic gases and substances inhibiting biological processes, especially for prolonged experiments, accumulate. Considering this, and also the fact that changes in diurnal temperature, illumination, and irradiation with ultraviolet rays must occur just as on Mars, and 18-liter low-pressure exobiological chamber was used in which the simulation of space conditions is more complete, exact, and automatic.

A series of interesting experiments was conducted in this "Fotostat" chamber. The most important conclusion must be regarded as the following: with a continual replacement of gas in the chamber (that is, in order that it contain about 0.0005--0.0002 percent oxygen) at a pressure of 0.01 atm, not only can bacterial life, but even the simplest one-celled animals that require oxygen. And whether the gaseous environment consists mainly of nitrogen or carbon dioxide plays no essential role. Thus, the continuous presence of oxygen in an environment in /155 amounts that are four-five million times smaller than in the earth environment at the surface proves to be sufficient for the existence of some representatives of animal life.

Experiments in Fotostat showed also that the main factor blocking the multiplication and development of life on Mars is not temperature, and not the gaseous composition of the atmosphere and radiation, but the deficiency of moisture, rapidly evaporating at the low atmospheric pressure. To more fully clarify the role of moisture in "Martian" conditions, it is necessary to more exactly know the diurnal moisture regime on Mars and whether water is present in the ground and in soils.

The data allow us to conclude that the physical environment at the surface of Mars, in spite of its severity, is not a barrier on the path of the development of life similar to terrestrial life, especially bearing in mind the exceptional adaptivity and plasticity of one-celled animals.

Conditions of other planets will be simulated in the Fotostat chamber in the future.

## CAN AN ARTIFICIAL ATMOSPHERE BE PRODUCED ON THE MOON? /156

It is virtually impossible to produce an artificial lunar atmosphere (on the scale of the entire moon), since the mass of the atmosphere (at the surface density which we have on earth) would be 0.4 of the mass of the earth's atmosphere, that is, 0.4 times $5 \cdot 10^{15}$ tons. Though the surface of the moon is 15 times smaller than the earth's surface, the force of gravity on the moon is one-sixth of the earth's and to produce the required atmospheric pressure the lunar atmosphere would have to be six times thicker. Hence we find that its mass would be 0.4 of the earth's atmospheric mass.

What does this number of $2 \cdot 10^{15}$ tons mean? This is two million billion tons. In order to visualize this more easily, we point out that our country can extract this amount of coal (at present extraction rates) only in four million years. But even if it were possible in some way to produce this atmosphere, it would very rapidly dissipate owing to the weak lunar attraction. Therefore, in the age of the direct study of the moon we can speak only of producing individual isolated sections and rooms (buildings or caverns) with an artificial atmosphere where lunar station personnel could live and work.

# CHANGES IN THE MARTIAN ATMOSPHERE /157

N. N. Semenov, Academician

Let us ask ourselves this question: is it realistic in a relatively short time, let us say, in several decades, to produce on Mars an atmosphere and climate suitable for human life? This above all means producing several hundreds of trillions of tons of oxygen. And the Martian atmosphere will contain just as much oxygen as is found in the earth's atmosphere. The oxygen can be obtained by the water that is present on Mars. Calculation shows that if on Mars the number of thermal nuclear power plants are built which would generate an amount of electric power ten thousand times greater than now is being generated on earth, and if this energy is used toward the electrolysis of water, then the required amount of oxygen could be produced in several decades.

I do not know whether mankind needs to master Mars; perhaps mankind will find a better use for excess energy and I cite this example only for you the reader to feel how grandiose are the goals that mankind can set for itself in mastering inexhaustible sources of energy.

# UNIVERSALITY OF LIFE



V. F. Kuprevich, Corresponding Member
of the USSR Academy of Sciences

First of all we must solve in principle whether life beyond our earth is possible. Thus far there has been only one realistic "yes" vote available to us. It was given by the cosmic voyagers -- meteorites. They in general are similar to more or less common earth rocks. Some of them, especially the so-called chondrites, contain highly complex organic polymers approximating new nucleic acids, or nucleotides. Chondrites have been found to contain formations repeating the shape, architecture, and size of charred spores certain fungi, down to as far as the bud spore at the apex of this pseudospore. Of course, no at all competent mycologist or microbiologist believes that the formation of polymers this complex or the amazing repetition of life forms in a meteorite represents the play of chance. These objects have nothing in common with druses or other similar artificial objects.

Interesting work has been done in institutes of the USSR Academy of Sciences and other centers: living organisms have been exposed to vaccum and very low temperatures. These experiments show that under such influences that are, in our view, unfavorable many organisms remain alive. And with respect to some of them in general no below-freezing temperatures were found that were capable of killing them. The question arose: what is this -- chance or adaptation, if one can so phrase it, to "astropolitical" existence when organisms can potentially leave their planet and migrate to another? Evidently, this is an adaptation.

There is yet another circumstance which must be referred to when we are speaking about life in the universe. The point is that in some respects the evolution of living matter on a planet came to a climax about two billion years ago. I have in mind the biochemical apparatus of living matter, the fundamental biochemical processes. As recent investigations have shown, several amino acids, in particular, aspargic acid, glutamic acid, glycine, proline, valine, and several others have proved to be extremely stable. They can be preserved up to 20-30 million years without any substantial changes. Even a fossil mollusk subjected to detailed examinations in laboratories in the United States had a myosine-adenosine triphosphate system in its muscles, that is, the same system that we use. Thus, 25 million years ago a mollusk gained energy for its active life in the same way as is done today. Or a second example: paleontological data indicate that photosynthesizing organisms on earth functioned actively about 1.5-2 billion years ago. At the very dawn of the origin of life and the formation of the primitive organisms, the process of photosynthesis had already existed in about the same form as it does today. "Chloroplasts" of the primitive creatures transformed energy of sunlight into energy of organic compounds just as today the dahlias that grow in your windowsill do successfully. /164

Using isotope measurements it was found that organisms capable of photosynthesis and reduction of sulfates existed about two billion years. What does this mean? First of all, it means that the evolution of biochemical processes, metabolism, was mainly climaxed very very long ago and only the speciation process continue its development. Evolution followed the path of improving the nervous system and probably has far from culminated along this avenue. Accordingly, biochemical processes associated with the activity of a nerve cell evidently will evolve and improve still further.

In order to undertake the subtle and highly complex biochemical processes in living matter at the level as is done today required an extreme long period. If we assume that the earth existed 4-5 billion years ago, then this time is clearly insufficient to conclude the evolution of several of the most important biochemical processes during the period extending from the present back 2 billion years. In fact, some of this time is accounted for by a period when owing to high temperature life on earth could not have existed.

The conclusion suggests itself that life exists everywhere in the universe and that living matter adapted to low and super low temperatures. And this means that in universal space there are possible "living voyagers," "homeless" representatives of life. They are spores or other forms, germs of life which wandering through space await a favorable opportunity to populate a given planet, if they are "fortunate".

And therefore the suspicion arises: have certain primitive /165 forms of living matter that had already gone through the prolonged pathway of biochemical evolution been transported from space at the earliest stages of the emergence of life on earth?

Here are some thoughts about other forms of life based not on carbon, as on earth, but on other elements.

It appears to me that in principle we cannot deny the possibility of constructing life on the basis of other elements; of these the most suitable is silicon. It is very widespread in nature, but in our earth conditions proves to be inapplicable for construction of living creatures. But in other conditions, silicon can prove to be a quite suitable foundation on which to construct the edifice of life. However, I believe that "silicon" rational and nonrational creatures do not exist in the solar system. This is the fate of other worlds.

What can we say about life on the moon?

It has been found that the lunar surface is coated with a material marked by extremely low thermal conductivity. Therefore, the moon expends its internal energy very economically. The impression is gained that under this warm garment protecting the "body" of the moon from cosmic influences, life cannot only be preserved, but also actively develop -- at some depth from the surface. Moreover, whatever the living creatures, they are also capable of evolving in these conditions. It is difficult to say how far evolution has gone. But since at a depth of several meters the temperature is not only constant, but probably above freezing, evolution is altogether possible. However, even a relatively low temperature does not impede the development of life. It is sufficient to recall the conditions of mountainous Antarctica, far from devoid of life.

The birth of life is involved inseparately with water. And therefore the question arises: is there water on the moon?

In the initial periods of planetary existence, during the fusion of matter a large amount of "primitive" water was formed. /166
Therefore, water exists on all planets without exception, including also on the moon. It has been calculated that up to 2-3 cubic kilometers of water were formed on each square kilometer of the surface of any planet during its formative period. With respect to some planets, the fate of this mass of water is unknown. In particular, the moon may have lost its water. But if we take note of the heat-insulating surficial cover on the moon, the earth's natural satellite must have a reserve of moisture, of course in the form of ice lying at some depth. It is not precluded that there is also water in the liquid form on the moon. Therefore, I believe that the basic, very essential condition for the development of life -- the availability of water -- has been met for the moon.

It appears to me that simple nitrogen and carbon compounds can exist on the moon -- ammonia and hydrocarbons, which perhaps were produced at one time by conditions suitable for the formation of life on the moon. But even if conditions for the formation of life were unfavorable on the moon, we cannot but consider that life may have been brought from space onto the moon during the billions of years of existence along with cosmic dust or large meteorites, which joined to the absence of atmosphere were preserved upon falling onto the moon's surface.

There are no open expanses of water on Mars. But this does not at all mean that Mars has no water. It is evidently in the solid state under the soil.

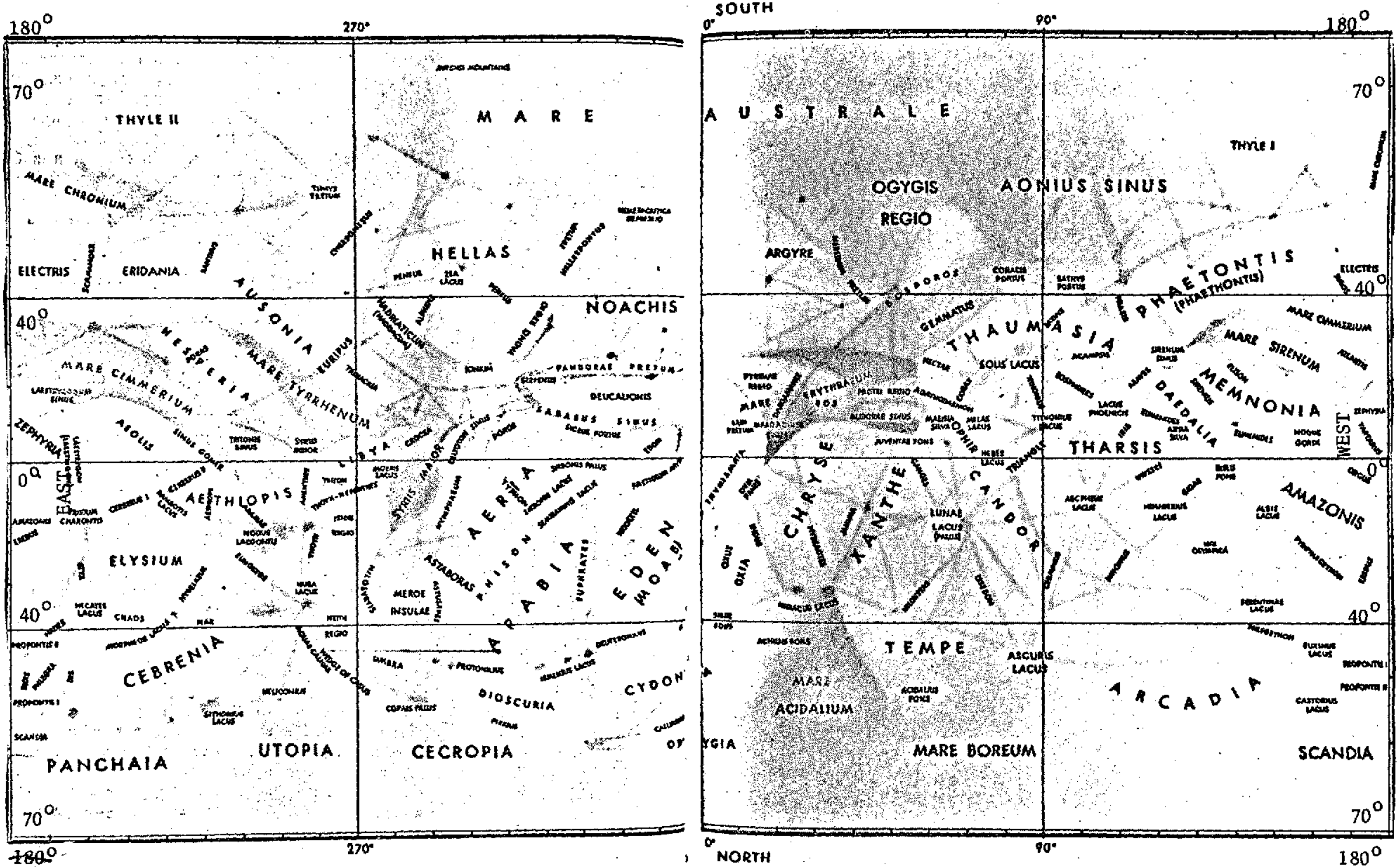
The question that always arises when we are talking about Mars and which often must be deliberately omitted, is the question of the canals of Mars. The origin of the regular formations extending from one hemisphere to another cannot be explained by any natural causes. This is the product of a rational will.

Saprophytic life requiring the production of organic material in certain amounts for its existence can be sustained in Martian conditions only when a well-developed system of /167
irrigation is present. And when we view the regular system of canal on the planet, naturally on analogy we reach the conclusion of structures erected by rational creatures.

Usually astronomers, physicists, mathematicians, and chemists express themselves about life on Mars or on other planets. And in this lies the diversity of the expressions. All "nonbiologists" attempt to populate Mars and other planets with earth creatures, that is, creatures that have adapted to the specific conditions of life on earth. And indeed that altogether ignore the degree of adaptation of earth creatures. But still on earth there are niches where they could not be life. In petroleum, in gasoline, even at the bottom of the deep ocean, in hot springs, in uranium ore, in a solution of sulfuric acid, in an atmosphere of methane or ammonia -- everywhere we find life. Why then do we artificially limit the possibility of the adaptation of life to conditions of other planets.

Astronomers populate Mars with lichens. This, in their view, is the main and only representative of plant life on a desert planet. It must be remembered that lichens appear on earth at the close of the Cretaceous Period when the world of vertebrates already existed. And this is understandable: lichens which are a complex of fungus and alga are extremely sensitive organisms. They do not tolerate the slightest, even the most subtle impurities of unusual gases in the atmosphere; they are sensitive to any chemical reagents.

In large cities -- in streets and in parks -- you do not find lichens on trees, while in the countryside they grow directly on roofs. This is the first sign that the city atmosphere is contaminated with gases that are given off at enterprises and are discharged into the air. Chemical analysis does not afford a more exact determination of their quality than do lichens. And astronomers populate Mars with such sensitive and capricious organisms!....




Photomap of Mars with the amazing network of canals
(after E. Slipher)

Areas which are assumed to be covered with vegetation on Mars are populated, of course, not by lichens, but by some higher plants, most likely cultivated plants. And therefore -- we must speak of the Martians that cultivate these plants. The plant kingdom cannot exist anywhere for long time without saprophytes (plants that do not require carbon from the air, but use it from radioorganic compounds; the most familiar saprophyte representatives are the bacteria and the fungi). Autotrophes -- organisms feed on inorganic compounds -- are always accompanied by saprophytes. This is an elementary fact. /170

I believe that the natural conditions on Mars permitted the development of an intricate complex of plants and animals, including rational creatures. And the Martians, if they did not die as a result of some catastrophe, all had a stage of development comparable with man. It is obvious that Martians have engaged in great transforming projects on their planet for quite a long time. Mankind has not been able to achieve such projects: I have in mind the Martian irrigation system.

I share the hypothesis of I. S. Shklovskiy on the artificial origin of one or both of the satellites of Mars. We can state with a high degree of probability that even in our time Mars has been populated by living creatures, possibly, rational creatures. This is indicated, in particular, by the sudden appearance on the map of Mars of the Laocoon node -- a dark area similar in size to the Ukraine. How could dark plant cover have formed over such an extensive area in one or two seasons? This is possible if there are extremely active creatures and necessary facilities available, let alone technical facilities.

It can be suggested that in Martian conditions the primary synthesis of organic matter and the accumulation of energy needed for a saprophytic population are accomplished in ways different than on earth. Besides the energy of the known regions of the solar spectrum used by earth plants, Martian autotrophes possibly combine radiation energy over a broader range of frequencies. In primary synthesis energy of unusual kinds of radiation can also be combined, in particular, ultraviolet rays penetrating to the surface of the planet owing to the low atmospheric density. It is possible that the oxides of iron, in particular, ferric hydroxide $Fe(OH)_3$, widespread on Mars are used as a source of water and oxygen. Perhaps, for example, dehydration is carried out:

$$Fe(OH)_3 \xrightarrow{\text{dehydration}} FeO \cdot OH \cdot H_2O;$$

$$2Fe \cdot OH \xrightarrow{\text{further dehydration}} Fe_2O_3 + H_2O.$$

The presence on Mars of given autotrophic living species in my view is obligatory. An autotrophic, in our earthly understanding, plant kingdom must be accompanied by a saprophytic population, similar to our earth bacteria, fungi, or animals, systematically producing organic material all the way to starting simple compounds. Otherwise the surface of the planet would even in the course of a millemium have been so sludged with organic /171 matter that the further development of the autotrophic, let us say plant, kingdom would be impossible.

I do not exclude the presence of presence of some forms of life on Jupiter and its numerous satellites. I would wish in this connection to again recall the exceptional plasticity of life, its unbounded adaptation to habitats. Only the first stage in the assimilation of matter from the environment is difficult, but the unlimited number of attempts that mastering the environment by newer and newer life forms ensures victory.

In truth there are no conditions that would be insurmountable for living matter. Darwin's principle of the variability of living creatures and pathways of adaptation to the environment evidently is mandatory for the entire universe. Laws established by the great English scientist are not less applicable for space than the laws of gravity or the conservation of energy and matter.

Interplanetary space is not empty, in spite of its high vacuum. In it there is present in gaseous or solid form matter, which can constitute a substrate for living matter. Complex organic polymers closely resembling the polymers produced by living matter or identical to it may have existed for many millions of years on asteroids and cosmic dust. There is a possibility of the continuous presence in space -- in interplanetary or interstellar space -- of germs of life, in forms unknown to us, reliably protected by a strong shell and capable of exchanging with their environment, for example, in terms of energy.

Life is a space phenomenon. As we have already pointed out, more than 2 billion years ago living matter combined energy of solar rays in the process of photosynthesis. Somewhat shorter periods of existence have been established, judging from the traces of strands on the valves of mollusks, for the mechanism of extracting energy from a compound of ATP /adenosine triphosphate/ type. Whereas, in what environment over what time intervals do the processes culminating billions of years ago in the creation of an apparatus underlying present life processes occur?

Evidently, living matter, when settling on any substrate, in any environment whose conditions admit of a primordial population, battle with its environment and along the pathways of unbounded evolution and perfection will produce the entire chain of living organisms, all the way up to a rational creature. This is the irreversible law of nature.

## PLANETS AND LIFE /164

A. I. Oparin, Academician

Forty five years ago I read a report in the Russian Botanical Society. I remembered that I expressed the certainty that our concept of the origin of life will change markedly when man enters space. Encountering other worlds, extra-terrestrial facts will give science invaluable material. Of course, I then could scarcely name the actual time schedules for the beginning of the space age. The idea of the direct study of other planets was then only a dream, the dream of a scientist, the dream of a man striving to understand himself and the universe.

I do not believe that biologically we differ in any way from people who lived a thousand years ago. But our power over nature has increased immeasurably. This fact has come about via a social, and not a biological, process. The stormy surge in development of Soviet science is the best proof of this.

Until quite recently it was believed that Venus is one of the most promising planets for the study of extra-terrestrial life. Actually, the favorable location in the solar system, weight, mass, a nearly exact circular orbit -- all this suggests conditions in which our earth exists. Therefore it was assumed /165 that evolution on this planet proceeded along the same avenue as on earth. However, nothing could be said with confidence. And still quite recently several different hypotheses existed concerning Venus. Whether it was covered with ice, or whether this was a continuous ocean, or a dissected land -- all was hypothetical. And only recently have we gained incontrovertible data. What do they tell us?

First of all, I must annoy writers of science fiction who evidently have placed great hopes on Venus. Signals obtained from there convince us that the possibility of the emergence, and therefore, the existence of life there is extremely small. But the same data are of enormous interest to science, for they show the altogether different forms of evolution which scarcely could have taken place on such a scale on earth. Today we are correct in categorically stating: evolution can take place in different ways on different planets.

Our neighbor evidently evolved in a somewhat different way and may today even be altogether different from earth.

The Gospel according to St. John begins thusly: "In the beginning was the word...." If one writes a scientific bible, a scientific history of the origin of life, it would begin in a different way: "In the beginning there was carbon." The evolu- /166 tion of reduced forms of carbon, hydrocarbons, then led to the emergence of life on earth.

Evolution evidently did not occur on Venus. There carbon is present in an entirely oxide form; no reduced forms have been found; and therefore the evolution of carbon compounds even in the initial stage is improbable on Venus.

Does this mean that one must abandon all our illusions about life on Venus? No. We have obtained very important, valuable data, but to say that we know this planet precisely of course cannot be done. Life, once emerging, can evolve, by adapting to given conditions. It is not excluded that complex highly organized carbon organic compounds may exist in the solid rocks of Venus. But at the high temperatures that have been detected at the surface of this planet they doubtless must have been subjected to decomposition, and their products would have been detected in the atmosphere. Unfortunately, thus far they have not been detected.

But perhaps life is capable of developing not only from carbon compounds? It may be that the "trunk of the tree of life" /167 is capable of growth on another, non-carbon, basis? Why not then, why should not we fantasize about this as well. But we do not know anything about other forms of life. There are no scientifically valid data on this at all. One may or may not believe in non-carbon forms of life. I am a scientist. For me faith is not enough. I must know precisely. And today this is what I know. All data of physicochemical investigations tell us that there cannot be other forms of compounds leading to the development of life. We have found compounds of reduced carbon on other celestial bodies, for example, in meteorites. Complex organic compounds have been detected in them. Therefore, the evolution of carbon compounds in some other worlds has proceeded quite far.

Amazing fact! It means that an objective regular trend toward the development of life exists in the universe, that where conditions are favorable life must inevitably arise. Our earth life is one branch of this general development of matter.

# NEW FINDINGS IN PLANETARY CHEMISTRY /172

A. P. Vinogradov, Academician

Until recently, the greatest interest in space chemistry was of course the asteroidal belt. It is precisely from here that the only cosmic material, in the form of varied meteorites, has reached the hands of man.

The material of meteorites retains features of its origin. In it all cosmic events over an enormous interval of time were "recorded" -- from the preplanetary stage to our day. Studies of meteorites have essentially opened up an entirely new field of knowledge, which promises to tell the entire history of matter in space.

Most stony meteorites consist of silicate droplets -- chondrules (hence their name, chondrites). Meteorites are encountered with the same chemical composition as chondrites, but not of grainy structure, and there are also basaltic meteorites (achondrites) that are similar to the basic rock of earth in structure and composition (basalt, dolirite /sic/). But there are also so-called mixed or iron-stony (stony-iron) meteorites that are an agglomeration of iron-nickel alloy with silicate material in various ratios, and finally there are of course the iron meteorites proper. The question naturally arises: what are the conditions under which all these varies bodies were formed?

It appears to us that with cooling of the plasmic protoplanetary substances ejected by the sun cooled down, the independent condensation of silicate droplets occurred -- the chondrules of stony meteorites and droplets of the iron-nickel alloy. These alloys, not with the example of silicate droplets, exhibit great thermal conductivity and other properties by means of which they readily merge into large masses, forming feritic meteorites. Iron-stony meteorites resulted from the agglomeration of "ready" stony meteorites with ferrite-nickel alloy.

If one attempts to answer the question as to the origin of the asteroidal belt, then we can say that these are remains from the "creation" of the planets or fragments of a celestial body blasted to smithereens. Chondrites with their grainy structure cannot be fragments of a large cosmic body. In this case the chondrule-droplets would disappear under the effect of pressure. Therefore it can be assumed that all chondrites were formed during the cooling of solar plasma, that is to say, they passed only through the meteoritic stage. Thus they are not the products of any magmatic differentiation of material.

The history of basaltic meteorites is altogether different. The formation of these "space wanderers" cannot be represented without their melting from chondritic material. But where did this process occur? Most likely, on the "moons", the large /173
asteroids. This means that basaltic meteorites passed not only through the meteoritic stage, but also the planetary stage. But this problem also applies to iron meteorites. Thus, the asteroid belt contains at least two kinds of silicate materials -- one kind passed only through the meteoritic stage, while the other also passed through the planetary stage.

Investigations using automatic interplanetary stations have provided the greatest success in the study of the moon. The lunar landscape with its circular structures now well known to everyone evidently will be discovered on all planets of the earth type. A controversy has gone on for more than 100 years over the question of the origin of the rocky landscape of the moon, and above all of the craters, as we know. It has not ended even today.

Two hypotheses are in competition, the volcanic and the meteoritic origin of the craters.

Comparison of the moon's craters with large meteorites and volcanic craters on earth convinces us that large lunar craters are of volcanic origin. Due to studies made with the Soviet automatic Luna-10 and Luna-12 stations, we have been able to determine the general nature of the rocks in the surface of our natural satellite. Lunar rocks, as we can see from the results of gamma-radiation recording, are classified among the main rocks of the earth's crust -- basalts.

Thanks to the flight of Apollo-11, investigators obtained rock from the lunar surface. These rocks were recognized as volcanic, having crystallized from a melt. In their composition, the most prominent are feldspar, pyroxene, and ilmenite, that is, they contain noticeable much iron and titanium. Based on petrographic, mineralogical, and chemical composition, the rocks in the lunar surface are classified in the group of basalts, and their chemical composition with respect to the structure of certain components coincides more precisely with the chemical composition of basaltic minerals. This means, first of all, that /174
rocks in the lunar mare are lava flows formed during the eruption of volcanoes, and secondly the thought that possibly basaltic meteorites fell on the earth from the moon is by no means absurd.

More than one fantastic tale has been written about the canals on Mars. A series of automatic laboratories have been sent toward this planet in our times. However, thus far we know little about it, just as before. We only know that below-freezing temperatures predominate on the Martian surface. Light gas molecules escape into space, therefore the small Martian atmosphere is hundreds of times less thick than the earth's and contains mainly carbon dioxide. The existence of polar caps and their disappearance in spring indicates the presence of ice, snow, or water, and more probably, $CO_2$ -- therefore the polar caps indicate that the Martian atmosphere contains some small amount of water vapor. Ice, snow, and water alter the external appearance of the Martian surface in relation to season. Photographs of the Martian surface with its numerous large craters shows a similarity to the lunar landscape. Evidently, small chainlets of these craters appear to us as canals owing to optical aberration. It is improbable that regions in which life is distributed will be discovered on this planet.

The discovery on the Martian surface of numerous craters is one of the most interesting finds of our time. Photographs made by automatic stations have revealed more than 300 craters of different sizes to investigators. White patches or bands, probably of snow, have been detected in the polar regions around the crater ridges. It has also been found that the mountains on Mars are more shallow and lower than on the moon.

Venus approaches earth in size, but it lies closer to the sun. It is assumed that regions with uneven terrain, mountain chains, and obviously also craters exist on it, since Venus has a thick atmosphere. The composition of the thick cloud cover of this planet remains a puzzle. According to numerous data, this /175 layer must consist of all the water that is on Venus. But thus far it is not clear in which forms -- ice crystals or water droplets. Under the cloud cover of the planet's surface there extends the Venusian atmosphere proper. Thanks to the Soviet Venera-4, Venera-5, and Venera-6 Space Stations it was possible to obtain the first information on its composition.

Owing to the closer proximity of Venus to the sun, its effective temperature is higher than on earth. In spite of other factors, this was responsible for the passage into the atmosphere of Venus of large amounts of water and carbon dioxide -- the atmosphere on Venus is 94-97 percent $CO_2$. This atmosphere must absorb enormous amounts of solar radiation, and due to this the temperature of the surface of Venus is about $500^\circ$ C. At the same time photodissociation of water and carbon dioxide have occurred. The oxygen formed in these processes is partially absorbed by the rocks on the Venusian surface. But hydrogen in these conditions of high temperature and the absence of a magnetic field escapes from the atmosphere, which in this way loses water. All this led to self-heating of the atmosphere, to the formation of the "greenhouse effect."

The distance to the sun thus played an important role in the formation of the dissimilar atmospheres on earth and on Venus. Under the conditions of the "corrosive" atmosphere of Venus, its rocks must have been subjected to profound disintegration, and the entire surface has been appreciably leveled.

Thus, planets in the inner region of the solar system possess shells. On the moon this is a partially basaltic crust, and on the earth -- a crust, hydrosphere, and atmosphere, while on Venus -- a thick atmosphere and obviously an earth type crust with volcanic craters (otherwise from whence would the gases of its atmosphere come from?), while on Mars -- an earth type crust (craters!), and possibly remains of a hydrosphere and atmosphere.

The primordially cooled material of the planets was differentiated in a single geological process into shells -- core, mantle, earth crust, hydrosphere, and atmosphere. But what was /176 the mechanism of this process? How did material comprising its external shells rise to the surface from a planet that was solid as a whole? It has been shown geochemically that this could have taken place through the melting out of the materials from the depths of a planet due to heat generated by radioactive elements. And this process occurred by the zone-melting principle. It was accompanied by degassing. We calculate that the effusive basalt (during volcanic eruptions on earth) transports about 7 percent water by weight, or about 20 percent by volume. Along with the water other vapors and gases are distilled off. On planets like Mars and earth, as a rule they are combined with rocks. Secondly atmospheres formed: an oxygen atmosphere on earth under the effect of life, while on Venus a heavy carbon dioxide atmosphere on exposure to solar heat. On the other planets the atmosphere disappeared entirely due to a numer of factors.

There is yet another factor that plays a distinctive chemical role in planetary evolution -- cosmic radiation, so-called solar wind, and also the ultraviolet radiation from the sun. Several years ago microalgae and other microorganisms were found in several meteorites. Incidentally, it was possible to show that these were organisms of terrestrial origin. They happened to be present in the meteorites after they have fallen on earth. But the discussions caused by these discoveries only grow hotter, since bitumenlike material was found in carbonaceous meteorites; and from the bitumenlike material organic compounds were isolated, highly complex, but optically inactive. Hence suggestions were made that these were compounds that were witnesses to former life in space.

All however turned out quite differently. It was shown experimentally that if mixtures of water and many gases ordinarily encountered in volcanic exhalations are irradiated with ultraviolet, electrons, and protons, the same compounds are formed as were discovered in carbonaceous meteorites. It can be imagined that in the early stages of planetary development when the thickness of the atmospheres was still limited, and the intensity of the "solar wind" was significant, such numerous compounds were synthesized. On earth the thick nitrogen-oxygen atmosphere emerged secondarily and, therefore, there was a time when this abiogenic synthesis on earth also occurred. It prepared for the appearance of the biosphere. /177

It is very difficult to formulate in brief what life is. But doubtless I have in mind only the aqueous-carbon type of life. What other kinds of life exist in the universe thus far no one knows. It is even unknown whether they exist at all. Earth life owes its origin to the characteristics of its principal substrate -- the properties of water and carbon. Actually, water is the most amazing liquid man knows. On the other hand, carbon is the only chemical element capable of forming millions of diverse compounds. This feature of carbon plays an extremely vital role in forming life with its optically active organic molecules.

But water and carbon would still not yet be sufficient for the development of life. A thick atmosphere, an ozone screen, the magnetic belt around the earth, and many other features of our planet promoted the development of life and protected it against penetrating ultraviolet radiation from the sun, and exposure to electrons, protons, and other radiation. Thus a unique structure of space -- the biosphere emerged, which then was responsible for the development of life occurring by chance.

## TECTITES -- COSMIC GLASS /173

G. G. Vorob'yev, Candidate
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Tectites are pieces of dark green or black glass, ranging in size from a filbert to a large walnut. They maybe in the shape of hollow spheres, onions, pears, dumbbells, and tiny plates. They lie on the surface of the earth, and also in relatively young geological deposits: they are especially numerous tectites in Australia, Czechoslovakia, and the Philippines.

At one time it was believed that tectites were volcanic glasses, obsidians; sometimes they were even taken as black diamonds. But now no longer is there any doubt that tectites could not have been formed in earth conditions. The birthplace of tectites is space. This was possible to establish by investigating the chemical composition of tectites and comparing it with the composition of earth volcanic rock and impactites -- products of meteoritic and nuclear explosions.

In 1958 American scientist V. Barnes published a simple logic table in which he collected the main arguments "pro" and "con" the cosmic origin of tectites. It graphically showed that known data agrees best with the space theory.

We continued this study and assembled extensive literature and placed it in microcopies and in codes on hand-punched cards. /174
The processing of the chemical part of these data uniquely established the relationship of tectites with space. The experiment was repeated on a Minsk computer and again the same results.

Tectite composition is quite distinctive. A chemical rose (one of the graphic methods of representing the composition of minerals and rock) shows that tectites are to some extent similar to acidic volcanic rocks and impactites, but strictly speaking they still differ markedly from them. For example, even though tectites can be classified as acidic rocks, they also contain typical trace elements of a basic character, like nickel, chromium, and cobalt; tectites contain very little volatile components. The water content is one-hundredth of that in glasses of volcanic origin, and one-tenth of that in impactites.

From the physicochemical point of view, tectites are a solid solution of oxides of various metals in silicic acid. However, sometimes disseminated pure silicon dioxide is encountered in them -- lechatelierite, which until recently was found only in impactites and fulgurites (products of a lightning stroke in sand); inclusions of a compact modification of silica -- coesite -- were also detected. /175

The author of this article discovered in tectites collected in the Philippines inclusions of oxidized meteoritic iron in which the American investigators identified typical cosmic materials: kamasite (nickelous iron) and schreibersite (iron phosphide). Finally, quite recently other American scientists had detected inclusions of zirconium dioxide in tectites -- baddeleyite, a mineral until recently encountered only in artificial glasses. Sometimes bubbles of carbon dioxide are found in tectites; moreover, one of the laboratories in the Kola Branch of the USSR Academy of Sciences was able to detect petroleum asphalt in tectites! Incidentally, the true significance of this sensational discovery is as yet too early to evaluate: only one thing is beyond doubt, that it goes beyond the problem of tectites.

Tectites are always encountered in aggregations. These aggregations form a field of approximately elliptical shape; drops of the most diverse composition can be found in this field, but the composition of the tectites themselves changes only very slightly. It has been found that tectites fall at small angles to the horizon even in a molten state in showers, where different fields were formed evidently at different times. It is not excluded that tectites were earth satellites for a while: then at some time their secondary fusion occurred, accompanied by the segregation of lechatelierite.

Of all existing theories of tectite formation, only two satisfy these facts. According to one of them (this theory is the most plausible), tectites were formed during volcanic or meteoritic eruptions on the moon. According to the other theory, tectites were formed on the earth during explosions of cosmic bodies -- giant meteorites, asteroids, or comets. Terrestrial theories are entirely rejected; neither has the theory according to which tectites are ordinary meteorites withstood criticism.

And thus, the relationship of tectites with space has already been proven; the next step will be the final elucidation of the mechanism by which they were formed. And if it turns out that the lunar theory is correct, then this will mean that man has held in his hand and analyzed lunar matter much earlier than the time the first soft landing on the surface of satellite was achieved.

# TRACES OF LIFE IN METEORITES /178

B. V. Timofeyev, Doctor of Geologo-Mineralogical Sciences

In recent years, interest has revived strongly in the study of meteorites, this "only material of cosmic origin that we can investigate as we investigate the biosphere, that is, in the full array of scientific knowledge," that we can learn about just as "deeply and fully as we can understand natural bodies of the biosphere in general." These words from the eminent Soviet scientist, Academician V. I. Vernadsky, uttered on 27 February 1938 at a session in the Academy of Sciences, forcefully come to our mind in our day -- the age of the widely ramifying exploration of space.

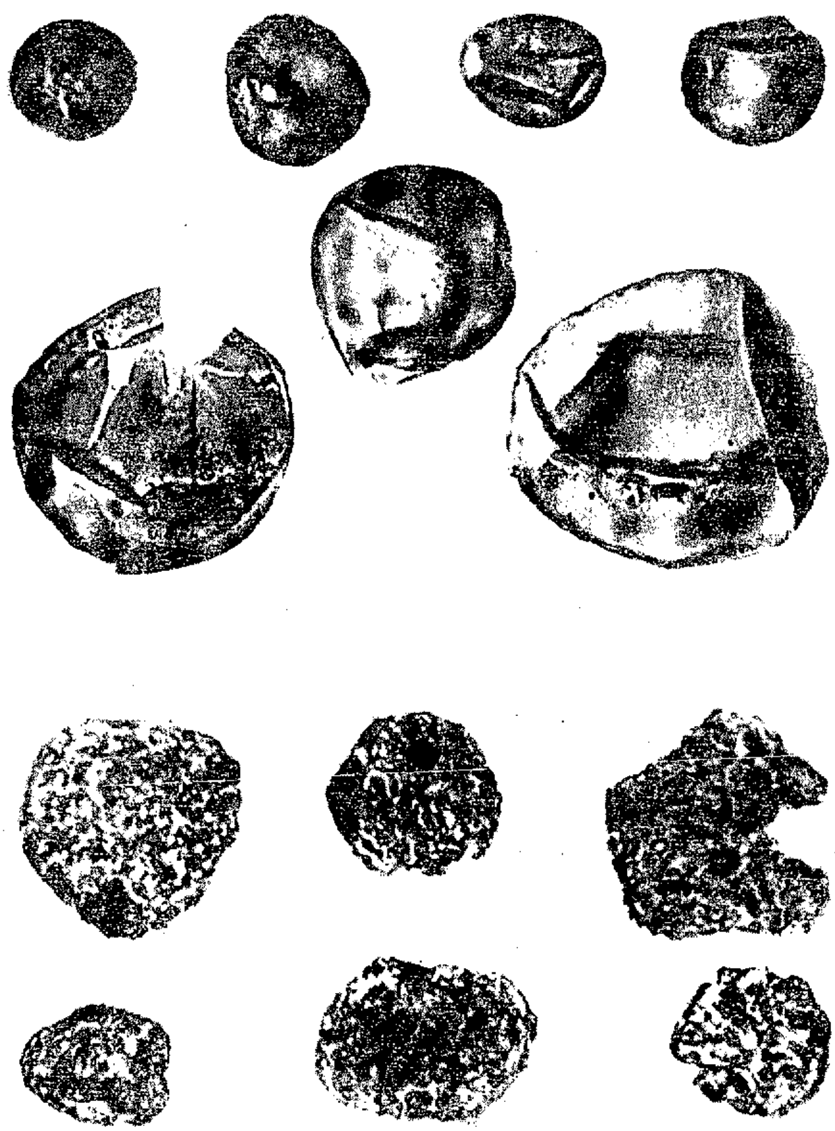
Great interest was aroused by stony meteorites, among which attention has been drawn to a small group of so-called carbonaceous chondrites. Carbonaceous meteorites contain much dispersed amorphous carbonaceous matter and hydrocarbons. Their carbon content can be as high as 5 percent. And carbon -- as we know -- is the most important constituent of organic matter. Still, it may also be of abiogenic origin. It is precisely this abiogenic origin that has been attributed to the carbonaceous matter in meteorites since the time of Berzelius, who in 1834 investigated the Alais meteorite, which had fallen in France on 15 March 1806. Subsequently work by Soviet and foreign scientists established the presence in carbonaceous chondrites of high-molecular hydrocarbons of the paraffin series. Moscow geochemist G. P. Vdovykin (1961), on investigating the carbonaceous meteorites Groznaya (fell on 28 June 1861 near the fortress of Groznaya, near the city of Groznyy in the Northern Caucasus) and Mighei (fell on 18 June 1889 in the village of Mighei in the Kherson area), detected in the former a vaseline-like substance with aromatic odor, and in the second -- bitumens compositionally similar to ozokerite. Even earlier, in 1890 soon after the fall of the meteorite Mighei, Yu. Simashko found -- using ether extraction -- 0.230 percent bitumenous substance, which he called erdelite, in a sample from this meteorite. Paraffin hydrocarbons similarly to those found in beeswax and apple skin wax were found in the carbonaceous meteorite Orgueil, which fell on 14 May 1864 in France near the city of Toulouse in the village of Orgueil. But ozokerite (mineral wax) and paraffin are in the view of most investigators a mixture of organic-origin hydrocarbons.

Even higher interest was stirred by reports of recent discoveries in carbonaceous and several other stony meteorites of so-called organized elements, outwardly resembling sporelike formations and certain one-celled algae. Reports of these finds appearing in 1961-1962 were based on observations made by scientists in the United States and the USSR at the same time, on different material and independently of each other.

Gradually the realm of the reliable came to light and the doubtful was discarded, and sometimes even the simply erroneous. Thus, for instance, often reports were made about finds in meteorites of living bacteria supposedly brought in from space. One such report spoke about the recent discovery (in 1962) of live bacteria of cosmic origin in the Sikhote-Alin iron meteorite. However, investigations made at the Institute of Microbiology, USSR Academy of Sciences, showed that thermophilic bacteria found in a piece of this meteorite 15 years after its fall were of terrestrial origin. /180

Another example of meteorite contamination was the discovery in the already-mentioned meteorite Orgueil of spores of a Cretaceous fern. It was obvious that it had fallen there from Cretaceous deposits onto which this meteorite had landed. Similar contaminations are possible when meteorites are stored in museums, when they are processed in laboratories, and especially palynological laboratories where the most diverse and different-aged materials are examined.

But still at the present time a wealth of material meriting close attention and confidence has been accumulated by researchers. Numerous microscopically small, chiefly spherical shells ("organized elements") have been extracted (with many precautions against contamination) and have been described from the carbonaceous chondrites Mighei, Orgueil, Groznaya, Staroye Boriskino, Ivuna, and Bokkeveld, from the stony meteorite Saratov, and several others, at the present time. Their examination and comparison with present and fossil spores of fungi, algae, one-celled algae, and other microorganisms known on earth lent some grounds for attributing extraterrestrial origin to these microscopic objects.



Various kinds of "organized elements" in meteorites

Results of micropaleophytological investigations of the meteorite Mighei made by the author of the present article are of interest. A fragment of the meteorite weighing 10 grams was found in a mortar and then treated with hydrofluoric acid (to disintegrate the silicates). Then came boiling in concentrated nitric acid and in potassium permanganate solution. By these operations, the test material was readied for separation of organic elements ("organized elements") from the mineral mass, which was achieved by separation of the precipitate in Sonstadt solution (specific gravity 2.2) on an electrical centrifuge for 10 minutes. The rpm was 3000.

Similarly, small samples (of 5-10 grams each) from the meteorites Staroye Boriskino, Groznaya, and Saratov were treated. In all cases a positive result was found.

More than a score spherical shells consisting of organic matter were disclosed in the meteorite Mighei. The shells are 10 to 70 microns in diameter and are colored yellow, yellow-gray, and dark-gray (down to black). They are single-layered, differing in thickness, but most often delicate, sometimes indented in clearly etched folds. The surface of the shells is smooth, and less often shagreen and finely nodulose. A round opening can be seen in one of these shapes -- an ostiole characteristic of certain one-celled algae and zygospores. Similar formations, though in smaller numbers, were extracted in the autumn of 1962 (a year and a half after the treatment of Mighei) from the following meteorites: Staroye /181
Boriskino, Groznaya, and Saratov. We note that the carbonaceous meteorite Staroye Boriskino gained wide fame in that Soviet petrographer L. G. Kvasha discovered the mineral chlorite, a hydrated silicate, in it and thus for the first time it was established that water of crystallization is present in meteorites; later, water of crystallization was detected in the meteorite Orgueil and other carbonaceous meteorites.

Nearly all "organized elements" outwardly resemble most closely the membranes of ancient Precambrian one-celled algae (protosphaeriidiae) -- tiny spheromorphids, and also the spores of certain fossil fungi. Protosphaeriidiae were widespread in the Upper Proterozoic (interval of 1.5-0.65 billion years on the absolute time scale) and less often in the strata of the Early Proterozoic (1.5--2.8 billion years). Accordingly, it was of interest to recall the data of Soviet scientist, professor E. K. Gerling, who used the argon method to fix the age of certain carbonaceous and stony the argon method to fix the ages of certain carbonaceous and stony meteorites (including Mighei and Saratov). It varies in the interval from 4.6 billion to 600 million years.

Foreign workers J. Klaus, B. Nagy, H. Urey, F. Staplin, and others thoroughly studied several well-known carbonaceous meteorites: Orgueil, Alais, Ivuna, Bokkeveld, Tonk, and several others. In their publications, these investigators give much prominence to the "organized elements" and to their description and discussion. Orgueil, one of the largest carbonaceous meteorites, received particularly detailed examination. It weighs 10 kg (the heaviest carbonaceous meteorite is the meteorite Murray, which fell in the state of Kentucky, United States, on 20 September 1950 -- 12.6 kg, and ranking third in weight is Mighei -- 7.948 kg). "Organized elements" from Orgueil and others that have been inspected consist of tiny spheromorphids, and their clusters, somewhat oval, barrel-shaped, and lenticular in form (ranging in size from 10 to 80 microns). Many are easily comparable with what Soviet scientists have found. In all foreign workers isolated more than 30 morphological types of "organized elements."

One finds remarkable the fact that many specialists (microbiologists, algologists, mycologists, and palynologists), on being acquainted with the "organized elements," refused to admit their similarity with earth organisms. Others, in contrast, assumed that the "organized elements" are the remains of organisms that lived and died on earth, but then were ejected into space during powerful volcanic eruptions. Most workers regard as the principal source of meteorites the belt of small planets -- the asteroids. The hypothesis is maintained that asteroids were formed due to the breakup of a once-existing large planet Phaeton. From this point of view, "organized elements" are the remains of the biosphere of this hypothetical planet.

Heated debates have continued over the discoveries of "organized elements" in meteorites, but it seems that all the debaters, sceptics, and optimists see the necessity for continuing the investigations that have been begun.

# POSSIBILITY OF LIFE ON MARS (GEOCENTRISM IN CURRENT BIOLOGY) /182

G. A. Tikhov, Corresponding Member of the
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In this article, the phrase "geocentrism in biology" has a special, allegorical meaning. By it we mean that earth is a kind of standard body most favorable for life, to some extent central, and deviations from its physical properties in either direction render now impossible the origination and existence of life. We must also understand in the same allegorical sense the word "topocentrism" used in this article, expressing the idea that the conditions for the origin and continuation of life and also its properties observed in any specific place on earth are regarded as standard for life in other places on earth.

Geocentrism in astronomy refers to the theory stating that the earth is the center of the entire visible universe. Thus, the theory of the ancient astronomers stating that the center of motion of the sun and the planets is the earth was given the term geocentric.

In 1543 a book by the great Polish astronomer Nikolai Copernicus was published, De revolutionibus orbium coelestium, in which it was shown that the center of rotation of the planets was not the earth, but the sun. This theory was referred as heliocentric (from the Greek word "helios" -- the sun). Now of course no one doubts that the earth is just another planet and that like other planets, it revolves around the sun.

However, the question arises: does the earth occupy an exceptional position among the planets in another respect? It is here that conscious or, more correctly, unconscious biological geocentricism appears in the views of some biologists and scientists in other specialties. These scientists speak and write to the effect that life in the solar system exists only on earth, motivated this viewpoint by the fact that physical conditions on other planets differ widely from terrestrial. However, this view is shared by far from all scientists and is the exception.

Here I present very interesting statements by the Greenwich Observatory director, Spenser Jones, from his book, Life in Other Worlds: "In attempts at explaining whether the existence of life in other worlds is possible, we meet with a difficulty, which is that we do not definitively know how life emerged on earth. Let us assume we were able to prove that on some other world the conditions essentially are the same as on earth. Would we be correct in assuming that since life appeared on earth, that invariably it must exist also on this world, though perhaps in forms other than /183
those with which we have been accustomed? On the other hand, if we were able to show that in the other world conditions differ so drastically from terrestrial that they rendered impossible the existence in the other world of the forms of life presently found on earth, would we be correct in assuming that this other world was altogether devoid of life? And would we not be correct to some extent if we assumed that the existing forms of life on earth developed by means of prolonged evolution, in accordance with existing conditions, so that if other conditions dominated somewhere else in the universe, then they may give rise to yet other forms of life?

I regard this passage from Spencer Jones as quite applicable from the philosophical as well as the scientific point of view. Moreover, one cannot apply the concepts of biological geocentrism to it.

Several opponents of the idea that life exists on other planets in the solar system write that the proof of the existence of life, for example, on the planet Mars, is not of fundamental importance, since perhaps this is a special case. But still we know that any view gains full force of persuasion only when it is proven in practice. Opponents of the idea that even plant life exists on Mars do not doubt that somewhere in boundless space life does exist, but we cannot now either show this by observation, nor in any forseeable time, and therefore they hope that even if the existence of life on Mars will be proven, this will only be a special case lacking general, fundamental importance. In this way, biological centrism will be saved. How similar is this to all the attempts to save geocentrism after the remarkable investigations of Copernicus, Kepler, and other leading figures in astronomy!

To clarify our thought, let us advance to the question of the possibility of plant life on the planet Mars, which is the closest, not counting Venus and the moon, neighbor of the earth, revolving around the sun at a distance ~~of~~ about one and a half times greater than the distance separating our planet from the sun.

Temperature conditions on Mars are roughly similar to the conditions in our Yakutia, where the lowest temperature of $-70^{\circ}$ C was recorded. However, there is incomparably less water on Mars than in Yakutia; the atmospheric density is ten times smaller than on earth; atmospheric humidity is much smaller than terrestrial; and oxygen that plays such a key role in earth life has virtually not been detected at all.

What kind of conclusion can we then draw? Without reflecting, it can be said at once: there is no life on Mars and there cannot be. Several other scientists have also reached this conclusion.

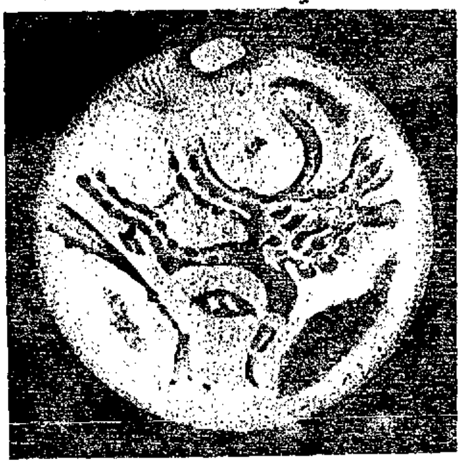
At the distance from us at which Mars lies, even with the most favorable position of Mars with respect to the earth, we can see only phenomena that depend on meteorological and plant processes. The activity of intelligent creatures could be detected only in the case when it reached an enormous scale.

And here phenomena of the following kind have been observed on Mars for many decades now: the appearance during the Martian autumn of a white polar cap in the corresponding hemisphere and the thawing of the cap with the onset of spring; sandstorms; the appearance and disappearance of the spring and summer coloration in the dark regions, receiving quite some time ago the incorrect name of "maria"; the slow change in the contours of some of these regions; and several other phenomena.

However, in the attempts at explaining these phenomena biological geocentrism was displayed by some scientists. This is not even geocentrism, but more properly topocentrism (the origin of this word derives from the Greek word "topos", which means "place"). Let us explain this idea. Here, for example, is some scientist studying the color of plants near a university city in which he works and teaches at the university. All university cities until recently were situated in locales with temperate or hot climate, and all botanists know that plants have quite definite color and spectral qualities. And here observations of Martian dark regions changing their color in relation to Martian times of the year disclose differences in color and spectrum from plants growing near university cities. The topocentric conclusion is altogether clear. Optical properties of Martian dark regions cannot be accounted for by the existence of vegetation.

In the 1940's a new science was born in the city of Alma-Ata -- astrobotany, that is, the science studying vegetation on celestial bodies. Since the first and most convenient celestial body for this study is the planet Mars, the founders of this science decided to investigate the optical properties of plants growing in high mountains and in the subarctic, where the climate somewhat approximates the severe Martian climate. Here it was also decided very early that the optical properties of these plants are close to the optical properties of the Martian dark regions. I will dwell on this somewhat more closely.

If we photographed a green plant in infrared (transred) rays, then it would show up completely white on the positive, as if covered with a thick layer of snow. But still if Mars was photo-



Drawing of Mars made by E. Antoniadi

Mars based on observations by N. P. Barabashov /185

graphed in the same conditions, on photographic plates, its dark regions would appear not white, but dark on the positive. Hence from the topocentric point of view we can conclude with every reason that there is no vegetation in the Martian dark regions. However, this is so only if we consider the question from the topocentric viewpoint; but from the scientific point of view, this is not at all so. Actually, scientists in university cities shot plants chiefly in the calendar summer time, while Martian plants were photographed at low temperatures, at times below zero. This is the reason for the difference in results. Actually, /186 infrared solar rays carry half its heat, and these rays would be too hot for earth plants in the summer; the plants would reject these rays and show up white when photographed at these wavelengths. But Martian plants need these rays even during the Martian summer and therefore they absorb them, do not reflect them externally, and show up dark on the photographic plate. This is the conclusion that suggests itself if we divorce ourselves from topocentrism. And this was checked by astrobotanists on plants in high mountains and the subarctic. Actually, many plants in these areas show up dark when photographed in infrared light.

It was further found that coniferous plants reflect infrared rays in winter twice as weakly as during summer. Finally, plants of the same species reflect infrared rays in different ways, depending on the altitude at which a particular plant grows. The higher the plant's habitat, the less infrared rays it reflects, the more intensely it absorbs them.

Thus, the so-called infrared phenomon found a complete explanation in the proceedings of the astrobotany sector, and topocentrism was completely eliminated in this matter.

We move on. Temperate climate plants significantly absorb some regions of the solar red ray spectrum, which is properly explained by the properties of green matter -- chlorophyll, that gives a green color to leaves and needles of plants. From the topocentric viewpoint, it would appear quite naturally to expect that the Martian dark regions also must display a considerable absorption of sunlight in the rays absorbed by the green matter in earth plants. Even K. A. Timiryazev asked American astronomers studying Mars whether they had seen chlorophyll absorption bands in the spectrum of Martian dark regions, assumed to be regions covered by vegetation. The answer was negative; this was explained as due to technical difficulties stemming from the small size of /187
the Martian image in the telescope. I myself searched for the chlorophyll absorption band in the spectrum of Martian dark regions in 1918-1920, using a 15-inch refractor in the Pulkovo Observatory: I ran into no technical difficulties, but I did not find the chlorophyll band. I had to conclude that there is no such band in the spectrum of Martian dark regions. Thus, from the biological topocentric viewpoint, it can be concluded that there is no vegetation on Mars.

Now let us examine whether this conclusion is correct from the scientific point of view.

Even in the past century our famed botanist K. A. Timiryazev showed that a plant grows mainly due to absorption of the solar rays in which the principal chlorophyll absorption band lies. Can it be concluded from this that there is no vegetation on Mars that is at all similar to terrestrial vegetation? We cannot yet make this conclusion for we have not yet even allowed for all the differences in the environmental conditions on these two planets. First of all, we must compare the temperature conditions. On the average it is much colder on Mars than on earth. Whereas it is sufficient for the life of a terrestrial plant in a temperate climate to absorb a relatively narrow region of red rays corresponding to the principal chlorophyll absorption band, in the severe Martian climate this is insufficient. A plant here must absorb, with the aid of special pigments, the heat rays of the sun which adjoin on one or the other side the main chlorophyll absorption band, and this band thus becomes only faintly detectable. This conclusion was also checked by us in the spectra of plants growing in the severe climate of high mountains and the subarctic.

Further, it has long since been known that in spring some regions of the planet Mars that are covered, as we believe, by vegetation are blue in color. From the topocentric viewpoint, this again contradicts the idea that vegetation exists on Mars. However, let us ponder this closely. If a plant strongly absorbs /188
red and contingent orange, yellow, and green rays close to the latter, which represent in fact one-third of solar heat, then in the plant-reflected "cold" light consisting of deep blue, blue, and violet rays, blue, deep blue, and even violet light plays a major role, and the plant obtains the corresponding coloration. That is why the Martian "dark regions" are blue or deep blue. Our observations in high mountains and literature data completely confirm the finding that among high-altitude plants there are considerable numbers of species that are blue.

Recently I read a short book, Obitel' Snegov /Snow Inhabitant/ by V. V. Agibalova and P. V. Kovalev. It described the natural setting of the Himalayas. It turned out that blue pine and blue poppies grow in the Himalayas. I had long known about the existence of blue spruce in Canada and we had even raised such spruce in Alma-Ata, but I learned about blue pine for the first time.

Thus, from the topocentric point of view the blue color of the Martian dark regions cannot be accounted for by vegetation, but on giving up topocentrism we quite plainly see that here we are dealing with the color of vegetation in cold countries.

Now we go from biological topocentrism to biological geocentrism. Statements are given orally and in writing such as, for example, the following: there is very little moisture and oxygen on Mars and therefore life does not and cannot exist there. Now we politely ask, who then told us that conditions of life on earth are the best of all possible conditions? I can imagine the following picture of fantasy: Martian academicians have gathered and are discussing the question of the chance of life on earth. An eminent Martian scientist stands up and says: "But is life really possible, given the high oxygen content in the earth's atmosphere shown by spectral analysis? In fact, all life on earth must suffocate and burn up. The situation is otherwise on our planet: our plants release oxygen through their roots into the soil, and it is from the soil that oxygen slowly enters into our atmosphere and gives us and all our animals the possibility of /189
breathing, without suffocating. The high water vapor content in the earth's atmosphere is also destructive to life. In fact, living bodies there must contain an enormous percentage of water and, given the high gravity on earth, this must impede the inception and existence of life."

The Martian scientists could thus discuss from their areocentric point of view (Ares is the Greek name for Mars). However, are not these discussions of the hypothetical Martian thinkers similar to what some of our scientists write about the chance of life on Mars? Some scientists, in discussing the possibility (or impossibility) of life on other planets in the solar system forget about the extreme ability of living creatures to adapt by evolution to the most diverse environmental conditions. Ultimately these conditions become the most stable for organisms. This conclusion is so self-evident that it does not further clarification. It suffices to recall the white polar bear and the African ape.

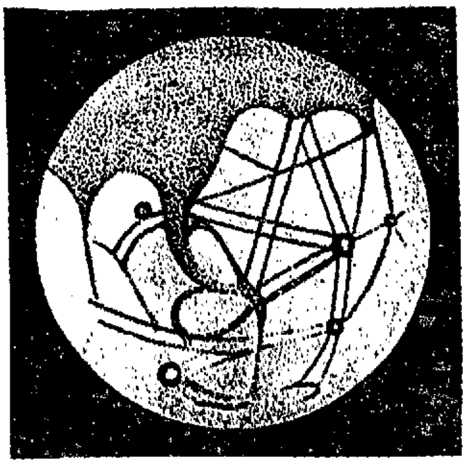
Thus, we must not at all regard as favorable for life on other planets the physical conditions which are similar to those on earth, and even those close to the large cities where scientists study basically the physiology of animals and plants. All their investigations are burdened with the idea that the conditions existing in these locations are the most favorable for life. It seems to me that it is time to give up this biological topocentrism, or in the broader sense, biological geocentrism.

We must study life in the extreme climatic zones of the earth and in artificial climate chambers where conditions would reproduce for the first time the external conditions on the planets Mars and Venus. It seems to me that these investigations would introduce much that is new into a question as important as the question of life on other planets.

MARS? NO, FIRST OF ALL -- EARTH! /184

V. Zhuravleva

It is quite likely that in science there has been nothing more daring and fantastic than hypotheses about Mars. Each of these hypotheses swept the world with tremendous speed, becoming known even to those who had no ideas at all about astronomy.



Canals on Mars as observed by Schiaparelli

How do these hypotheses spring up?

It would appear that it is not hard to answer this question. Like other hypotheses on the universe, suggestions as to the nature of Mars must /185 emerge with advances in astronomy and its observational facilities. However, "Martian" hypotheses had a very unusual fate. In contrast to other astronomical hypotheses, as a rule they have a plainly "earth" origin. In some sense they are a reflection of what exists on earth. All we need is to recall some historical facts and the birth of "Martian" hypotheses now no longer becomes a chain of stupefying sensations, but a quite curious principle.

1. 1869. Construction of the Suez Canal was at an end. And in the very next favorable opposition of Mars (1877), Italian astronomer Schiaparelli discovered a network of narrow black lines on Mars. Schiaparelli called them canals, not yet associating them with a definite concept of an artificial structure for the inflow of water.

Years pass. Schiaparelli continues to investigate the "canals" of Mars. In 1888 they already numbered 130 on the map of the Italian astronomer. Finally, 1893-1895. Schiaparelli firmly advances of the hypothesis of the artificial origin of the canals. In this same year (1894), American astronomer Percival Lowell establishes in the state of Arizona a special observatory to study Mars, particularly, its canals. /186

And thus the hypothesis of artificial canals on Mars was born in 1893-1895. But it was precisely at this time that the construction of Kiel Canal (1895) was completed and that the building of the Panama Canal was underway -- attracting worldwide attention. A chance coincidence? But here is an interesting detail: much later it was found that nearly a hundred years before Schiaparelli various observers plotted about 60 canals on the Martian map. But no one pronounced the word "canals" and no expressed an idea of their artificial origin. One had to await the beginning of the age of building large canals on earth. ... Only then did scientists discern canals in the dark straight lines crisscrossing the Martian continents!

2. The 1890's. Powerful searchlights with paraboloid reflection and silvered back surfaces were invented. Searchlight detachments were introduced into the armies of European nations. Light signalling began to be used in navies. Several years pass ... and now in the first years of the 20th century a sensational report appears in the newspapers: Several astronomers detected bright white points near the terminator (the boundary between /187 the illuminated and unilluminated regions) of Mars. Light signals? Thus many believe in any case.

But careful checking led to the conclusion that the bright points are not at all beams from Martian searchlights. No, these are simply clouds illuminated by the sun....

3. Beginning of the 1920's. The number of radio amateurs is climbing rapidly. Stable radio communications between continents has been achieved. The ether is filled with the call letters of short wave stations. In 1922 the method of superheterodyne reception for directional ultra short waves for the first time. Radio amateurs discovered the extremely large range of low-power radio receivers when operating at wavelengths shorter than 100 m.

And nearly almost at once -- in 1924 -- the world is again swept by a sensation: some radio stations have received radio signals from Mars! However, this time as well a check yields negative results: the "radio signals from Mars" prove to be a prank by amateur radio pranksters.

4. Talk about plant life on Mars began as early as 1860. But to move from talk to scientific hypotheses, several characteristics of Martian vegetation must be understood. In particular, it had to be explained why Martian plant life reflects /188 light differently than does terrestrial plant life.

This could be done only after the world-renown work by Luther Burbank and Ivan Vladimirovich Michurin, who in practice demonstrated the amazing adaptability of earth plants to environmental conditions. It is precisely after Burbank and Michurin that astrobotany was founded, predicting the character of Martian plant life.

5. 1937. Japanese observers recorded a bright flare on Mars. Thus far no hypotheses accounting for it were advanced.

1945. The poisonous clouds of atomic blasts rose over Hiroshima and Nagasaki.

1951 and 1954. Japanese observers again detected bright flares on Mars, and the first of these was accompanied by the appearance of a white cloud. The hypothesis was advanced that these ... atomic blasts.

6. 1945-1950. Propeller-driven aircraft is being replaced by jets. Projects for aircraft with atomic engines are being put forth. And in 1946 there appeared the hypothesis that the Tungus meteorite, which fell back in 1908, was a Martian nuclear rocket ship.

Quite likely, it is typical that this hypothesis appeared /189 precisely in 1946, and not in the 1920's and 1930's when a great deal of attention was being directed toward the Tungus meteorite ....

7. 1957-1958. The first artificial earth satellites are being launched one after the other. The phrase "artificial satellite" becomes incredibly popular. And in 1959 a Soviet scientist, Doctor of Physico-Mathematical Sciences I. S. Shklovskiy, advances the hypothesis that the Martian moons -- Phobos and Deimos -- are artificial satellites.

Again we must add the qualification: the "earth" origin, in general, does not at all detract from the significance of the

"Martian" hypotheses. Each of them has its own fate; each plays its own role in science. Some of these hypotheses are now only of historical value (for example, the hypothesis about the light signals); others became widely accepted (the hypotheses of the astrobotany); while still others are in need of verification (the hypothesis of the artificial origin of the satellites of Mars).

I wish to emphasis just one thing: however "daring" the Martian hypotheses appeared, they already reflect what man has done or discovered on earth.

# INTELLIGENCE ON MARS /190

F. Salisbury, professor (United States)

Not all researchers are agreed that forms of life can exist on Mars, and some believe Mars is uninhabitable. Actually, the arguments against life on Mars are convincing and well-known.

By way of an introduction to arguments on the chance of life on this planet, let us list five of them.

Temperature. The mean temperature on Mars is evidently nearly $-55^{\circ}$ C ($+15^{\circ}$ C on earth). It is also possible that, even though not one astronomer has yet directly seen the night side of Mars, the temperature of the entire planet can fall to $-80^{\circ}$ C not long after dusk. In the middle of the Martian summer, just past noon temperatures up to $+30^{\circ}$ C have been observed along the equator, but it is possible that some regions of Mars, for example, the Hellespont depression, are never heated above $0^{\circ}$. Can one imagine a form of life existing in conditions this cold? Some biologists believe this is impossible.

Atmosphere. Though temperature conditions on Mars seem to be poorly suited for life, atmospheric conditions appear to be even less favorable. As shown by flights of Mariner craft, total pressure is in the range 3-7 mb (atmospheric pressure on earth is 1000 mb). At this pressure water will evaporate rapidly at low temperatures.

The Martian atmosphere contains only very limited oxygen admixture, in the best of cases. True, many plants can live even without oxygen, but oxygen is necessary for most earth organisms.

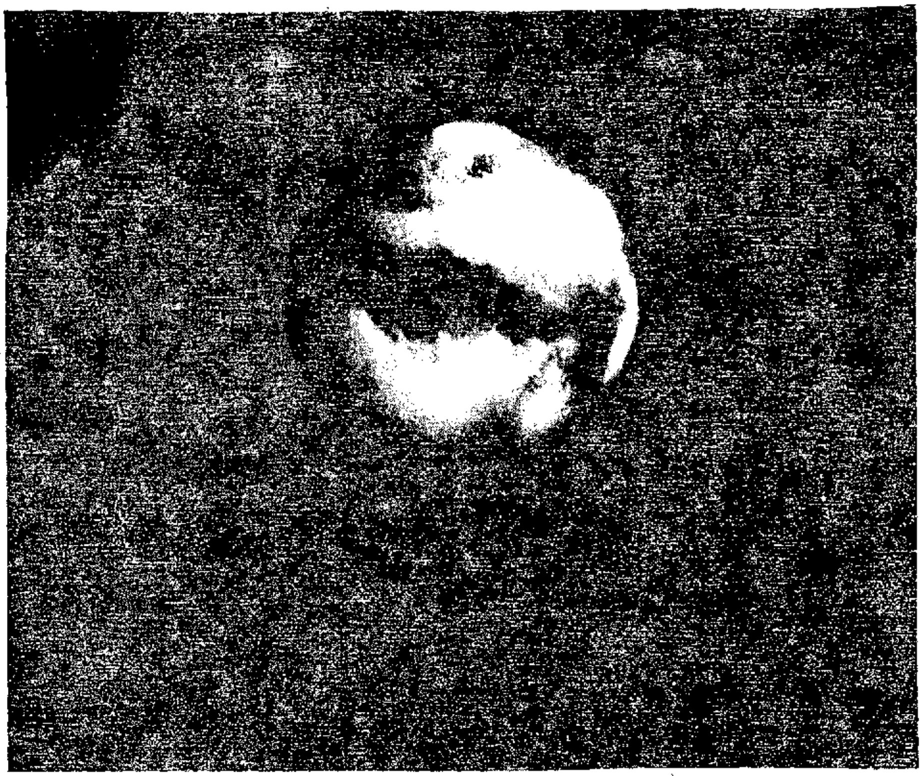
The Martian atmosphere probably contains small amounts of nitrogen and argon (though they unfortunately they have not been detected spectroscopically), but most of the atmosphere is evidently composed of carbon dioxide, which must favor Martian photosynthesis.

Water. For more than two hundred years astronomers have observed the forming of polar caps and have concluded that they consist of water. At one time it was believed that the caps could consist of solid carbon dioxide (dry ice), but this assumption has now been abandoned. Clouds of various types have been observed several times in the Martian atmosphere, evidently also consisting of ice crystals (on Mars clouds form very infrequently, while the earth is always partially covered by clouds). Quite recently water was detected spectroscopically in the Martian atmosphere, but the humidity there must be very low. Most astronomers state that rain never happens on Mars, though Dr. Slipher from Flagstaff Observatory in Arizona published photographs showing the darkening of regions of the Martian surface after the passage of clouds. This may indicate the wetting of soil by a humid atmosphere, though this event occurs truly seldom on Mars. We have not seen the movement of liquid water on the planet, although the movement of water from pole to pole actually occurs -- with thawing of the southern polar cap, the northern cap enlarges.

Ultraviolet radiation. Measurements made from high-altitude rockets showed that virtually all ultraviolet radiation of the sun must penetrate the rarefied Martian atmosphere down to the planet's surface. Ultraviolet radiation of this intensity must kill most earth species of bacteria in several minutes, while ordinary garden plants die in 3-4 hours. The level of cosmic radiation on Mars may prove to be higher than on earth, but as shown by most calculations it will not be dangerous to life.

Absence of erosion and craters. Photographs taken by Mariner/192 reveal that the Martian surface is dotted with craters, assumed to be of meteoritic origin. The landscape is very monotonous compared with the earth, since on Mars there are neither large mountain chains, nor canyons, nor desert plateaus, nor oceans, nor the other signs of erosion found on earth. Could it be that life emerged on a planet devoid of broad oceans? Could life exist on the surface of a planet with such a monotonous relief?

In spite of all these arguments, several observations speak in favor of life on Mars so persuasively that we are quite correct in re-examining all the objections raised above. The sections of the Martian surface astronomers have called maria disclose all signs of life.



This is how Mars looks on a modern photograph

The most remarkable feature of the maria is the annual cycle of change in coloration. During the Martian winter they grow dim or disappear, but with the onset of spring the polar caps start to recede, and then the "maria" soon begin darkening. This darkening advances toward the equator, while the polar cap retreats toward the pole. It is difficult to imagine for this phenomenon an explanation other than that the darkening wave is caused by moisture forming during the thawing of the polar cap.

On earth the spring renewal of plant life begins in the subtropical regions, and it moves toward the pole -- in a direction opposite to that on Mars. On earth the activation of plant life depends not on water, but on temperature, while on Mars water is of greater value.

The gradual advance of darkening from the edge of the polar cap toward the equator occurs at a constant rate, identical from year to year. On the average, the darkening front moves toward the equator at the rate of 35 km per day. This fact is remarkable in itself, since the wind velocity at the Martian surface (the movement of yellow dust clouds) is 48-200 km/hr and the form of gigantic cyclones is typical of the wind. All this appears to be some anomaly if we assume that darkening of the soil is caused by the transport of moisture from the polar caps by atmospheric currents.

In any case, the Martian "maria" with their color changes simply appear to be living. Physical theories advanced thus far in explanation of this phenomenon were rejected one after the other.

In recent years, we have been very busy studying the biochemistry of living organisms in our biological research, and we have been amazed by the high degree of uniformity we have found. The existing differences tend to become smoothed over and we can think of life as something that is essentially the same for all living organisms. But in the century past a biologist was more often amazed by the diversity he encountered. Many books were written to show and describe the adaptation of living creatures to the environment in which they lived. Here the general conclusion was evidently that living creatures adapt superlatively, and even sometimes in amazing ways to their environmental habitats. Will it therefore be logical to view life on Mars only from the standpoint of earth life? Since the Martian environment radically differs from ours, we must expect that life forms will also differ strongly from earth forms.

Sometimes the Martian "maria" are covered with a layer of yellow dust, but several days later they appear again. If they consist of Martian organisms, these organisms must either grow through the dust or "shake" it off. I have long since been amazed by the "density" of the Martian "maria" compared with the so-called deserts surrounding them. If the "maria" photographed so well through a red filter, then this means they consist of organisms covering the soil in a solid layer. This is quite evident if we observe our desert regions from an aircraft at the altitude at which individual plants cannot be differentiated.

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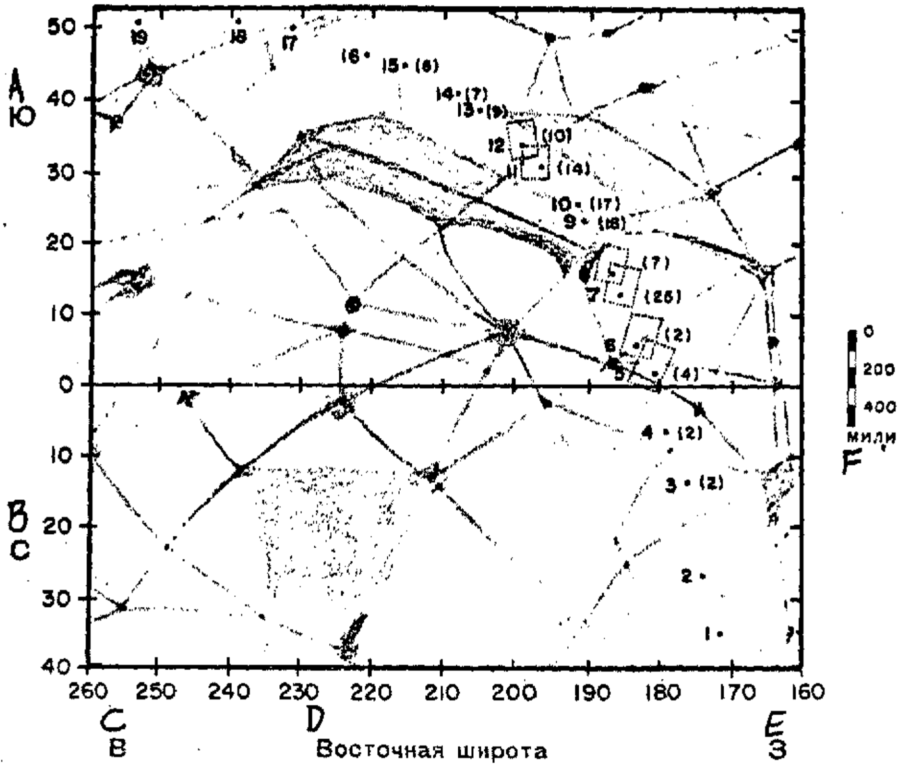



Regions of the Martian surface whose images were transmitted to earth by the Mariner 4 probe

KEY: A -- South
B -- North
C -- East
D -- East Latitute
E -- West
F -- miles

Sometimes rapid changes occurring over the span of several years are seen in the Martian "maria" and "deserts". For example, in 1952 a dark region the size of France appeared (Lucus Laocoon). /194 It appeared where there was a "desert" in 1948. If this incursion into a "desert" had been made by Martian plants, they evidently simply did not exist. This observation was so astounding that we could even ponder the thought of a Martian intelligence able to conquer part of the "desert" for itself with the aid of agronomy!

But before one can agree with such a radical idea, let us examine other arguments on the hypothesis of a lush plant life on the surface of Mars. Here there are three lines of argument which make this idea more acceptable than may be assumed at first glance.

Martian topography. May there not be microclimatic regions, for example, hot springs, that are a refuge for life on Mars? Of course, they are too small to account for the Martian "maria". But the craters we have seen on the photographs of Mars can be regarded as an ideal locale for life on the dry, cold, wind-swept planet. The temperatures at the bottom of a crater may be somewhat higher -- in part because the atmosphere there is more dense and in part owing to the heat radiation of the crater walls at night. If moisture can be collected along the rim of a crater at a high elevation where the night temperature becomes lower, then by thawing out high enough in the morning the moisture could stream down to the bottom. The impact of a meteorite may break up the surface into fine fragments and render it very porous so the water can percolate through the porous ground. In any case, the bottom of a crater will be well-protected against the wind and accompanying dust-storms.

Photographs made by Mariner craft show that craters are situated most densely in regions astronomers call maria.

In one way or the other, it is quite probable that life may have emerged at the bottom of craters and then may have moved onto the highlands between them. In very good visibility conditions Martian "maria" actually break up into a multitude of fine de- /195
tails, but we have no grounds for assuming that today life is limited to the bottom of Martian craters since the "maria" of Mars are too extensive for this explanation.

Ability of earth organisms to survive in extreme conditions. Life is much more resistant to extremal conditions than we ordinarily assume. Numerous observations have convinced us of this.

Doctor Sanford Siegel and his coworkers have experimented with a variety of artificial atmospheres, with temperature extremes and low humidities, ultraviolet radiation, and so on. In several of their experiments they tried to reproduce the assumed conditions on Mars. The pressure in their Martian simulator was at times as low as 16 mb, there was practically no oxygen, the temperature at night was $-25^{\circ}$ C, and $+25^{\circ}$ C -- during the day. In these conditions the seeds of some plants sprout, and winter rye yields shoots that continue to survive for 2-3 weeks, after which mold usually kills them. Molds flourish in these conditions and even complete their life cycles! Several bacteria also grow well.

Siegel and his colleagues found a most interesting fact: at low temperatures the absence of oxygen promotes the survival rate of certain organisms, while at a very low oxygen level -- low temperature for part of each day promotes the survival of organisms.

To study the effect of moisture content, Siegel raised a number of bacteria in saturated lithium chloride solutions. It was all the same whether moisture was obtained from these solutions, or from the air -- whose relative humidity was a fraction of a percent, or from water vapor at a pressure lower than 0.1 mm Hg at $265-270^{\circ}$ K. Warton and Ogayo observed a beetle capable of extracting water from air with an efficiency of 0.65 and of concentrating water in its organism at an efficiency of 0.99. These experiments enabled us to conclude that on Mars organisms are able to extract moisture from the atmosphere. It is also instructive to recall that our higher plants get along well in /196
extracting carbon dioxide from air, though its concentration in air is only 0.03 percent.

Doctor Morris Klein and I studied ultraviolet radiation and its effect on living organisms. We found that certain species of pine, and also certain desert species of agave can long tolerate exposure to a simulated Martian spectrum. Austrian pine, for example, showed nearly no damage after 635 hours of illumination with a xenon lamp at an intensity expected on Mars (including the ultraviolet spectral region). Many of the plants we studied died after 3-4 hours of this kind of irradiation; but those that survived showed that ultraviolet radiation cannot be regarded as a serious obstacle to the existence of life on Mars.

Hypotheses of possible mechanisms of adaptation. Here let us examine just one example. How can living creatures survive and participate in ecology in an environment containing no oxygen? Here we must ponder several solutions. For example, in their redox reactions supplying energy they can utilize some other element besides oxygen. Nitrogen has several degrees of oxidation and it can serve in biochemistry in this function, though less efficiently than oxygen. Almost any other element is suitable for this role to virtually the same extent: schemes utilizing either sulfur, iron, or phosphorus can be constructed.

Following another approach, let us imagine oxygen passing from one oxidation level to another so that it never takes on the gaseous (molecular) form. Long ago it was assumed that the reddish color of the Martian surface is due to the presence of iron oxides. Possibly, Martian photosynthesis transfers electrons from oxygen to iron without giving off gaseous oxygen. With further respiration or decomposition, electrons can be transferred in reverse, yielding iron oxide and releasing energy. It is easy to see all the difficulties in this explanation, but /197
this kind of scheme is possible and it permits cyclic ecology on a planet devoid of oxygen.

We can even set up its model on earth. A glass test tube with ooze containing photosynthesizing and decay organisms can remain always anaerobic. Photosynthesis provides the reducing energy, which is then utilized by the decay bacteria in their vital activity.

Perhaps we can only theoretically modify earth organisms for them to satisfy Martian conditions? A relatively new science -- physiological plant ecology, examining plant functions with respect to the ambient environment -- provides us with several opportunities. A knowledge of biochemistry is also of great assistance. First of all, we must state that theoretically it is much easier to modify higher plants in order that they correspond to the criteria advanced on the possibility of life on Mars than simple lichens. If higher plants could exist in spite of the nearly total absence of water and oxygen, at low temperatures and with the high amount of ultraviolet light, then at least they could grow up rapidly and propagate so that in this way we could account for the coloration of the Martian surface. Lichens, in contrast, would need enormous modifications before we could utilize them in accounting for the phenomenon we observe, while in their new form they would no longer resemble lichens.

Ultraviolet light, possibly, is the least serious of the unfavorable conditions on Mars. To eliminate its harmful effect, Martian organisms would have to acquire only some form of protective pigments. Such pigments found in certain fungal plants (parasites) of Death Valley withstand exposure either to ultraviolet light or gamma radiation, whose intensity is unknown on Mars. Studies of the hue of the colored contours of Martian /198 actually indicate that the system of pigmentation on the planet is homogeneous and not at all similar to that on earth.

We can relatively easily imagine modifications of plants oriented and adapted to the specific temperature conditions on Mars. Heat transfer between plants and their environment has been investigated in close detail, and the findings lead us to a very interesting conclusion on the heat yield. Owing to the very thin Martian atmosphere, heat transfer via convection or thermal conductivity is relatively minor, while transmission of latent heat through vaporization would be extremely negligible owing to the small amount of water.

Everything which lies on the Martian surface is under the continual influence of ambient radiation. Heating during the day occurs via the solar radiation reaching the planet (just as on earth), while cooling at night is caused mainly by the radiation of heat through the thin atmosphere devoid of water and ozone. And only the carbon dioxide gas can impede this radiation.

This, any adaptation of plants aimed at increasing the absorption of irradiated heat during the day and at decreasing heat transfer at night would be favorable. Rapid heating during the day would be facilitated by some system of pigmentation striving to bring the organisms closer to the state of absolute absorbers of rays -- a black body. Darkening during summer and the general gray hue of the coloration in the Martian regions, just as low reflectivity and infrared light, must be regarded as departures from this black color.

Martian plants must during the day expose a broad flat surface to sunlight. Owing to the low level of convection and thermal conductivity, a thin leaf appears to be the most suitable for this purpose. If this leaf at night were able to roll up into a tube (a phenomenon which, incidentally, is found also on earth), this would reduce the heat loss. Change of coloration at night (close to white) would have the same result and it is also observed on some plants on earth.

The temperatures on Mars at night fall off so sharply that in contrast to all available adaptations, not a single cold-blooded organism would be able to avoid freezing. The solution

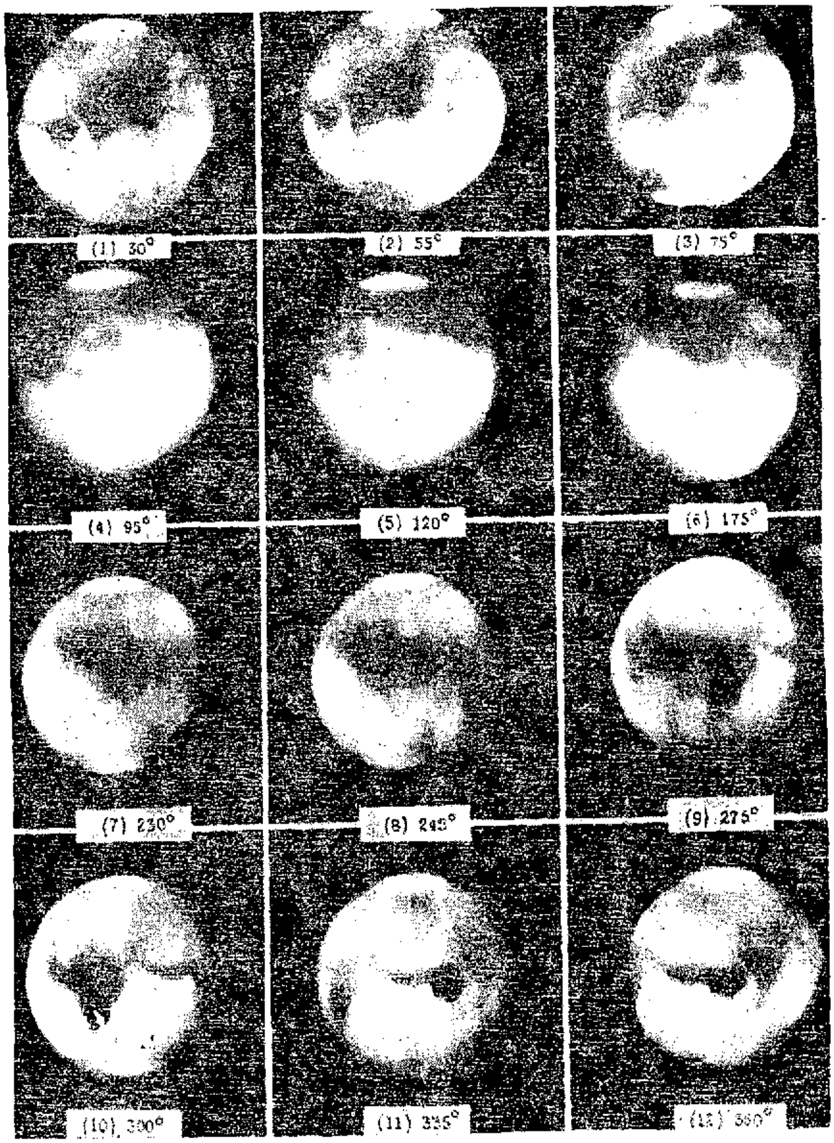
to this problem is not afforded by a freezing-point lowering substance dissolved in protoplasm. It would be simplest of all to imagine that plants, on freezing at night, thaw out during the day, and do not suffer from this at all. Again on earth such plants are in abundance. A good example are the lichens, mosses, and other lower forms which withstand intense frosts. Even certain species of high-mountain higher plant forms tolerate freezing. Most can withstand the lowest temperatures during winter, when their metabolism stops, but some can withstand freezing even at the peak of their growth. Evidently, the plants simply freeze into a solid state and then renew their life activity upon thawing. In this process, Martian plants /200
doubtless can preserve a large amount of energy, since evidently they would not expend it while frozen at night.

Water is the most vital factor for earth organisms. Change in coloration under the effect of polar cap thawing would seem to indicate that water also plays a major role for Martian organisms. Doubtless, there are no streams of water on the Martian surface that would supposedly flow from the polar caps since water would freeze at night and evaporate into the thin atmosphere (there are grounds to suggest that water only moistens the soil along the margins of the polar caps). Water would be able to travel along pipes laid by intelligent creatures, but before we can imagine such a situation we must be convinced of this.

There is the suggestion that plants themselves cause a certain rise in the moisture content of the atmosphere. Actually, this increase can be so slight that it does not explain the changes observed in the planet's coloration.

As a result, doubts have been raised concerning the role of water in Martian biochemistry. If water served there as the main solvent or medium in which reactions occur as on earth, the problem would actually be serious. The possible amount of water on Mars has been calculated based on the size of the polar caps and the water vapor content in the atmosphere.

These calculations indicate the following: water accessible to organisms is present to such a small extent that the organisms must be a fraction of a millimeter in thickness.




Photographs from whose details one can trace the rotation of Mars about its axis -- the cause of diurnal temperature fluctuations of its surface

However, the question arises as to whether water is incorporated in living organisms and whether in this case it is inaccessible for the formation of the polar caps. Water can also be part of ice crystals of the blue haze, but here it is also no longer available to plants. I was interested in the question of perhaps that water on Mars plays the role of a "vitamin" and not at all a fundamental solvent. The definite amounts of hydrogen and oxygen could be sufficient for the main reactions, but Martian biochemistry may not even depend on these elements as in the case of biochemical processes on earth.

The question as to whether water is the main solvent or whether it is a kind of "vitamin", just as the problem of the loss of water by Martian organisms, is most vital. The actual form of grassy plants depends on water. This can be estimated by observing how plants wilt. In actual fact, on earth plants are the main conductors of water from the soil to the atmosphere. Unquestionably, this phenomenon does not occur on Mars. There must be some single form of the adaptation of organisms to environmental conditions strictly limiting the loss of water by Martian plants. It is very difficult to visually trace this mechanism. Our plants lose water because they must absorb carbon dioxide gas. Since Martian plants doubtless require carbon dioxide as their carbon source, they must also encounter this problem.

At the present time we have a model that solves this problem. /201
Certain compounds, for example, hexadecanol, can be used to coat a lake with a monomolecular film preventing (or restricting) the evaporation of water, while oxygen and other gases can pass freely through this layer. Water loss is restricted, though the essential gas exchange will continue. It can be assumed that Martian plants are coated with just this kind of compound, which is necessary to retain water when carbon dioxide gas is being absorbed from the atmosphere.

It is possible that the most serious of these problems is the virtual absence of oxygen in the Martian atmosphere.

Strughold suggested that an inner atmosphere may be present in Martian plants, confining the oxygen obtained through photosynthesis, which then is utilized in respiratory processes. But how can an organism take up carbon dioxide gas and retain any other gas, for example, oxygen? And just as in the case of the anaerobic respiratory process, life must develop in the direction of the continuous evolution of carbon dioxide gas without any change whatever in ordinary processes of decomposition.

Only one of the many now-existing hypotheses is capable of explaining the existence of life on Mars. This hypothesis states that the main biochemical mechanisms of Martian life differ from earth life mechanisms.

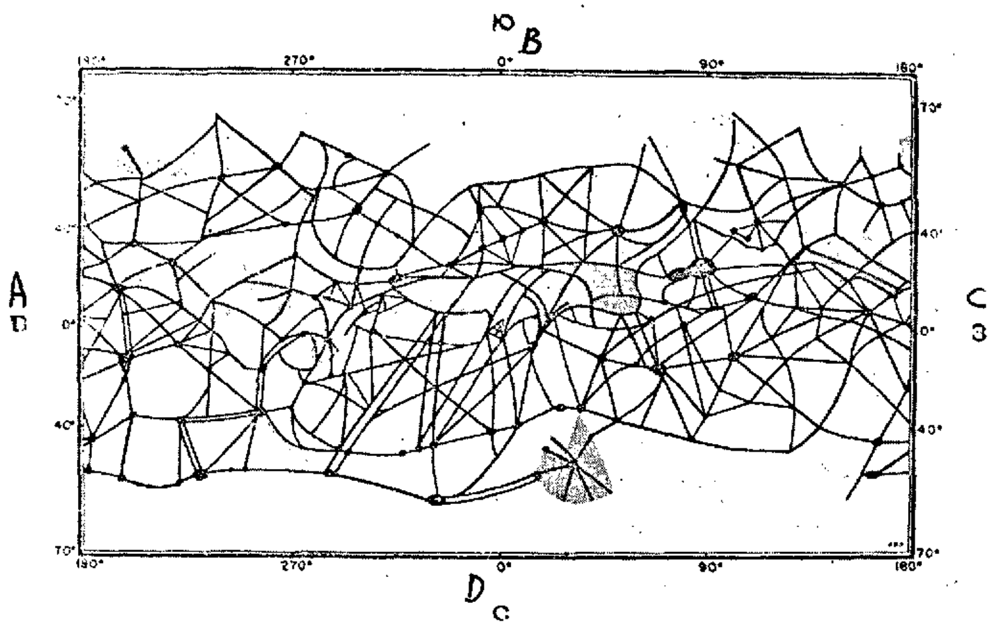
Martian organisms can split off oxygen from iron oxides contained in the soil of "deserts", just as oxygen is split off from water during photosynthesis in earth plants.

If these arguments compelled us to agree with the statement that lush and well-adapted vegetation is present on Mars, we could scarcely ignore the remaining members of the biological community. Animals can solve the biochemical problems of the Martian atmosphere just as the plants solve them. We can regard Martian "maria" as something analogous to our plant cover. But self-moving organisms are also possible in this biological setting.

Intelligence is the next step of the ladder. Everything hinges on the hypothesis of a flourishing plant life. If it exists, then we must admit that animals are also possible. And if there are animals, then we must recognize that for them the attainment of a level at which conscious interaction with the environment begins is a possibility, and we must call this reflective intelligence. Is there, however, intelligence on Mars?

Let us recall the constant speed of the darkening wave, beginning each Martian spring. Winds capable of carrying moisture in the planet's atmosphere do not show this constant velocity. Is it not caused by the presence of some technical irrigation system built by Martians? The Lucus Laocoon is a phenomenon so fantastic that we must reckon with the chance that it resulted from some irrigation project on Mars.

I pondered long over why the "maria" plotted on the map by astronomers have no topographic connection whatever with the surface that the photographs taken by Mariner 4 reveal to us. Natural plant cover of course must relate to Martian topography, just as on earth. Whether any of the physical theories is valid -- the volcanic hypothesis, the hypothesis of nitrogen oxides, or the hypothesis of hygroscopic substances -- the "maria" would prove to be intimately associated with the topography. Is not the presence of a rational agriculture the only explanation for the absence of this connection?




/202

Network of Martian canals from the observations of P. Lowell

KEY: A -- East
B -- South
C -- West
D -- North

The canals on Mars have long been an object of controversy as possible proof of intelligent life. For this closed network of lines which becomes visible when conditions in our atmosphere and on the surface of Mars favor it, there must be some explanation. Two of its features are particularly remarkable, as noted by astronomers. The first is the closed network, in which only a very few lines simply break off in the "deserts" without linking up with any other. Second, the lines of the network intersect in dark spots, called oases by the astronomers. The moon is dotted with craters, but there is nothing similar to the network of canals on the moon. And this network is akin to the ejection lines or the crevasses between meteoritic craters on the earth's surface. But cities at the bottoms of craters would really be connected by a network of communications, including a subterranean irrigation system along which lie "farms" (this can perhaps explain the width of the canals, often extending to 30-50 km in size).

Recently suggestions have appeared to the effect that the Martian satellites may be artificial. These two satellites travel in nearly circular equatorial orbits, and in this sense they differ from the natural satellites of any other planet in /203
our solar system. They are at a close distance from Mars and are very small in size. If Phobos and Deimos do not reflect more light than our moon, then they possibly are 16 and 8 km in diameter. If their reflectivity is higher than the moon's, then they are even smaller. Acceleration during the motion of one of these satellites takes place in such a way that there are grounds to assume that the satellite is a hollow sphere (the I. S. Shklovskiy hypothesis).

The circumstances behind the discovery are of high interest. In 1862, during the opposition in the 19th century most favorable for observation, the satellites could not be detected, but in 1877 during the next opposition, the observatory in Asaph Hall discovered both satellites at the same time. Can the failure in 1862 be attributed to the imperfection in the then-existing telescopes, or can it be assumed that the satellites were inserted into orbit between 1862 and 1877?

Sometimes very bright light flares are observed on the surface of Mars. At times they last for 5 minutes, but soon thereafter a spreading white cloud emerges. One must carefully scan the literature on astronomy to determine precisely how often these phenomena have been observed. Upon an examination of limited material, I gained the impression that since 1938 -- the first case known to me -- this event was repeated 10 to 12 times. The brightness of the flare is nearly equivalent to the brightness of a hydrogen bomb blast. This bright, bluish-white light could scarcely be volcanic, and the explosion of a fallen meteorite could not have lasted that long. But at the same time it is impossible to imagine that this phenomenon was actually a thermonuclear explosion. The coincidence in historical periods is in itself so fantastic that it represents the decisive argument against such an explanation. But are these so-called flares on the Martian surface a natural phenomenon, or some product of intelligence? Probably, we will have to investigate Mars directly to answer this question.

Thus, we have a complex network of canals, seasonal changes in color, satellites, and bright light flares which are followed by white clouds.

The simplest explanation for all of this is that there is life on Mars. Judging from the data we have recently obtained, it appears to me quite possible to conclude there may also be intelligence there not inferior to ours or even surpassing it. This possibility is strong enough to justify every effort to reach Mars and to investigate its surface.

We must do everything possible in order that by applying scientific principles to explore phenomena suggesting the possibility of life and intelligence on this planet. These are the methods of science and in the past they have proven fruitful. Perhaps we will find a natural explanation for all these amazing observations. But at the same time, we must deal with the possibility that intelligent life will be found on Mars.

We must mentally, emotionally, and scientifically prepare ourselves for the chance that our nearest cosmic neighbor may perhaps be populated by intelligent creatures.

RADAR PROBES OF PLANETS /194

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Signals reflected from various areas of a planet's surface have different delay times and different Doppler frequency shifts. This leads to broadening of the reflected-signal spectrum. The extent of this broadening is proportional to the visible rate of planetary rotation and therefore measurements of this broadening make it possible to determine the elements of planetary rotation.

Radio signals reflected from the moon were first picked up in 1946 by Z. Bay in Hungary and by J. de Witt and E. Stodall, in the United States. These subsequent radar studies determined the distance to the moon to a precision of several hundreds of meters and also established the reflectivity of the lunar surface and its individual components. Owing to the much greater distance in the case of radar studies of Venus, the product of the intensity of the flux of beamed radio waves by receiver sensitivity had to be increased by a factor of about 10,000,000.

Successful radar measurements of Venus were made for the first time in 1961 in the Institute of Radio Technology and Electronics /195 of the USSR Academy of Sciences jointly with a number of organizations; in the United States -- in the Jet Propulsion Laboratory of the California Institute of Technology, in the Lincoln Laboratory of the Massachusetts Institute of Technology; and also in England -- in the Jodrell-Bank Observatory.

One of the results of these measurements and the measurements made in subsequent years was a much greater refinement in the astronomical unit. The astronomical unit, equal to the mean earth-to-sun distance, is the fundamental basis for measuring distances in the solar system. However, even though the elements of planetary orbits have been determined in astronomical units extremely precisely, the astronomical unit itself, repeatedly determined by various astronomical methods, is characterized by relatively low precision. Radar measurements of the astronomical unit afforded the most precise data.

The problem of the rotation of Venus, of long standing and quite involved, was solved with radar.

Attempts to determine the rate of Venusian rotation about its axis from the movement of details along its disk in visible /196 as well as in ultraviolet rays, and also based on the displacements of spectral lines were made several times. However, they all yielded contradictory results. The cloud cover tightly enveloping the planet's surface interfered.

Radar measurements brought clarity into this problem as well. The rotational rate was determined from the Doppler shift in the frequency of signals reflected from various parts of the planet. It turned out that in contrast to the earth and most planets in the solar system, Venus rotates opposite to the direction in which it revolves about the sun. This rotation is very slow: the planet makes one rotation abouts its axis every 245 earth days.

The planet's axis of rotation proves to be close to the perpendicular to the orbital plane. Thus, seasonal changes on it, like the earth seasons of the year, must not be well-defined.

In these experiments the reflectivity of the Venusian surface was also determined at wavelengths 12 to 75 cm. It was found to lie within the limits of 10-15 percent, which corresponds to = 3.7 - 5.0 and does not contradict the result obtained by measuring the polarization of intrinsic radio emission. /197

In 1962, radar probes were made of Mercury in the Institute of Radio Technology and Electronics, confirming the value of the astronomical unit obtained by the radar probes of Venus, and gave a value for the reflectivity of the surface of Mercury close to the value for the lunar surface. Later, more detailed observations of Mercury made by G. Petengil afforded an unexpected result: it turned out that its period of rotation is $59 \pm 5$ earth days in the forward direction. This means that Mercury does not always face the sun with the same side, as was formerly believed. After this finding was reported, former optical observational results were analyzed again. It turned out that they agreed closely with the new data.

Radar observations of Mars and Jupiter were also made in observatories of the Soviet Union and the United States.

## CAN OUR PRESENCE BE DETECTED? /204

C. Sagan, professor (United States)

The inception of life is evidently a chance episode in the early development of our planet's surface. Only the most general conditions were needed for the broad "production" of complex organic molecules -- a reducing atmosphere composed of gases quite often encountered in space and certain amounts of liquid water. Judging from the earth's history, we can assume that if these conditions were dominant even for several hundreds of millions of years, the emergence of life would become probable. As far as we know, even much shorter time intervals would have been suitable.

However, besides the general starting environment, we must also look at other factors. If the surface temperature was too high, the ordinary organic molecules would be decomposed thermally at the same rate at which they were formed and there would be no liquid medium as a solvent for the first chemical reactions and as protection against primary ultraviolet radiation. If the surface temperature was too low, the chemical reactions familiar to us would have occurred at negligible rates, and the liquid medium would have frozen and would no longer be available. The freezing point of water can be reduced by adding salts to a solution. Therefore possible limits to liquid water as a medium for living systems and for adequate stability and rates of the reactions of organic compounds familiar to us must be regarded as temperatures from -50 to +100° C. Since on the day side of Mercury, for example, temperatures much higher than this dominate, then we have some grounds for thus far excluding the chance of life there.

Another factor is the temperature of the exosphere, the level beginning at which molecules fly off into space. If the exosphere temperature was very high, then the rate of volatilization of the planetary atmosphere would also be high. Its reducing atmosphere is preserved only for very short times, inadequate for the emergence of life. On Mercury the mass of the exosphere is so small and its temperature so high that any primitive reducing atmosphere, which the planet may have had at some time, would have dissipated quite long ago. In low-temperature environments more amazing types of biochemistry are possible. Water as a solvent can be replaced by liquid solutions of ammonia or hydrocarbons, and carbon compounds in a biochemical structure can be replaced by silicon compounds.

Our knowledge of planetary environments enables us now to strike Mercury and the lunar surface from among the possible foci of life. This is also probably true of Venus, the asteroids, and most of the other satellites in the solar system. But by applying negative judgments a priori, we must carefully see that we do not fall prey to the temptation of earthly analogy. There may be forms of chemistry and living systems on other planets which cannot even imagine. The best approach here is observation, and not deduction. /205

Can we detect living systems on earth with the aid of a remote observational station? The mass of the earth is $6 \cdot 10^{27}$ g; the atmosphere's mass is $5 \cdot 10^{21}$ g. But the mass of the biological material on the surface of the earth, based on the latest estimates, is only several times more than $10^{17}$ g. This is less than 0.0001 percent of the mass of the air and about $10^{-8}$ percent of the earth's mass. Thus, in spite of all our self-conceit, we are only a kind of biological rust adhering to the surface of our little planet and weighing much less than the invisible air surrounding us. However, we have subjugated and transformed the surface of our planet, have modified its appearance, and are preparing to abandon it in order to begin a long journey. Can our activity be observed from afar? Can our presence detected?

In the Martian sky the planet earth will be detectable as a very bright star, only somewhat less bright than Venus in the earth's sky. As we see the phases of the planet Venus, thus will the phases of the earth appear to a hypothetical Martian astronomer. Since the earth in the Martian sky is visible at a greater angle relative to the sun than is Venus for us, it would be easier to observe it from Mars than to observe Venus from earth. Earth will play the role of the morning and evening star, standing low in the Martian sky. Owing to the phases, it will be difficult to observe its surface at about noon local time, except for those cases when the earth is at a greater distance from Mars on the side of the sun. /206

Will our engineering installations -- dams, reservoirs, and cities -- be visible from the Martian observatory?

Owing to the turbulence in our atmosphere, even the largest telescope, the 200-inch reflecting telescope in Mount Palomar Observatory (California) can photograph on Mars objects not smaller than about 300 km across. The Martian atmosphere is much more rarefied than the terrestrial and it is possible that the resolving power of the Martian telescopes is less limited by atmospheric properties. The smallest object on earth that can be seen from Mars must have a diameter of several kilometers.

Photo of earth's surface taken from Gemini 7

1 -- Nile Valley
2 -- Nile Delta
3 -- Red Sea
4 -- Lake Ammer
5 -- Suez Canal
6 -- Sinai Peninsula
7 -- Dead Sea
8 -- Lake of Tiberias
9 -- Israel
10 -- Syria
11 -- Jordan
12 -- Lebanon
13 -- Turkey
14 -- Cyprus

The earth has been photographed already a number of times from space.

In the United States, a program of systematic earth photography by the Tiros and Nimbus series satellites was undertaken in order, by photographing the formation, movement, and dissipation of clouds, to improve weather forecasting. Sometimes structurally interesting cloud formations can be seen on photographs of the earth taken by the Tiros and Nimbus satellites. The earth's surface can be seen between the breaks in the clouds. But even if regions represented on photographs are related to areas of the earth where population and vegetation is the most dense, after the most careful scrutiny not the slightest sign of life could be seen on them.

New York looked like a desert, and India and Ceylon appeared lifeless. The same conclusions were confirmed hundreds of times after careful examination of photographs of densely settled regions in the earth: with a resolving power not more than several kilometers, no signs of life could be detected on earth!

A total of several hundred thousand photographs were made and examined in the Tiros series. On some of them objects whose diameters were not less than 2000 feet could be discerned. But of all these photographs, in only one were there distinct signs /207
of life on the earth. This photograph was taken by the Tiros 2 satellite over the forests near the Canadian city of Cochrane, on 4 April 1961. Several broad parallel lines could be seen in the upper left of the photograph, and another group of lines perpendicular to them. Lumberjacks had cut clearings in the Canadian forests a mile wide, separated by distances of 2 miles. Later, snow had fallen, emphasizing the contrast between the trees and the treeless clearings. But could signs of life from

the viewpoint of a Martian observer be detectable on even this single photograph, one out of a million? Could not the Martians actually imagine some geological process responsible for this picture? Even here, with a resolving power higher than that which the imaginary Martians have we cannot find definite proof that there is life on earth.

Our group investigated photographs taken by Nimbus satellites at maximum resolving power. When this indicator was several tenths of a kilometer, we could discern a recently built highway in Tennessee, the possible trail of a jet aircraft in the Davis Bay, the wake from a ship in the Red Sea, and also a linear formation along the northern coast of Morocco bearing all external signs of artificial peninsula, but proving to be a natural formation. With a resolving power of several tenths of a kilometer, signs of intelligent life on earth could be detected, but they were doubtful. A resolving power of 10 m and even higher is essential for convincing photographic proof of rational life on earth.

Can the night glow of our largest cities be detected -- New York, Moscow, Tokyo, Paris, London, and Chicago?

Let us assume that the artificial illumination of one of our largest cities is on the average ten times brighter than the light of the full moon and is limited to an area of 10 $km^2$. Then a Martian astronomer, on observing the night hemisphere of the earth could scarcely notice the little speck of light, appro- /209 ximately of stellar magnitude 16. But actually, owing to the scattering of sunlight by the illuminated earth hemisphere, the Martian astronomer in the best of cases could only detect weak signal at the limit of perception. Another factor capable of making our largest cities invisible is smog. Evidently, each time when a city becomes large enough for its night illumination to be detectable from Mars, the layer of contaminated air forming over it makes it invisible even at night. American astronaut Scott Carpenter was able to observe mountain paths and smoke from chimneys when passing over Tibet, but when he was over Southern California, he could not detect the slightest sign of Los Angeles.

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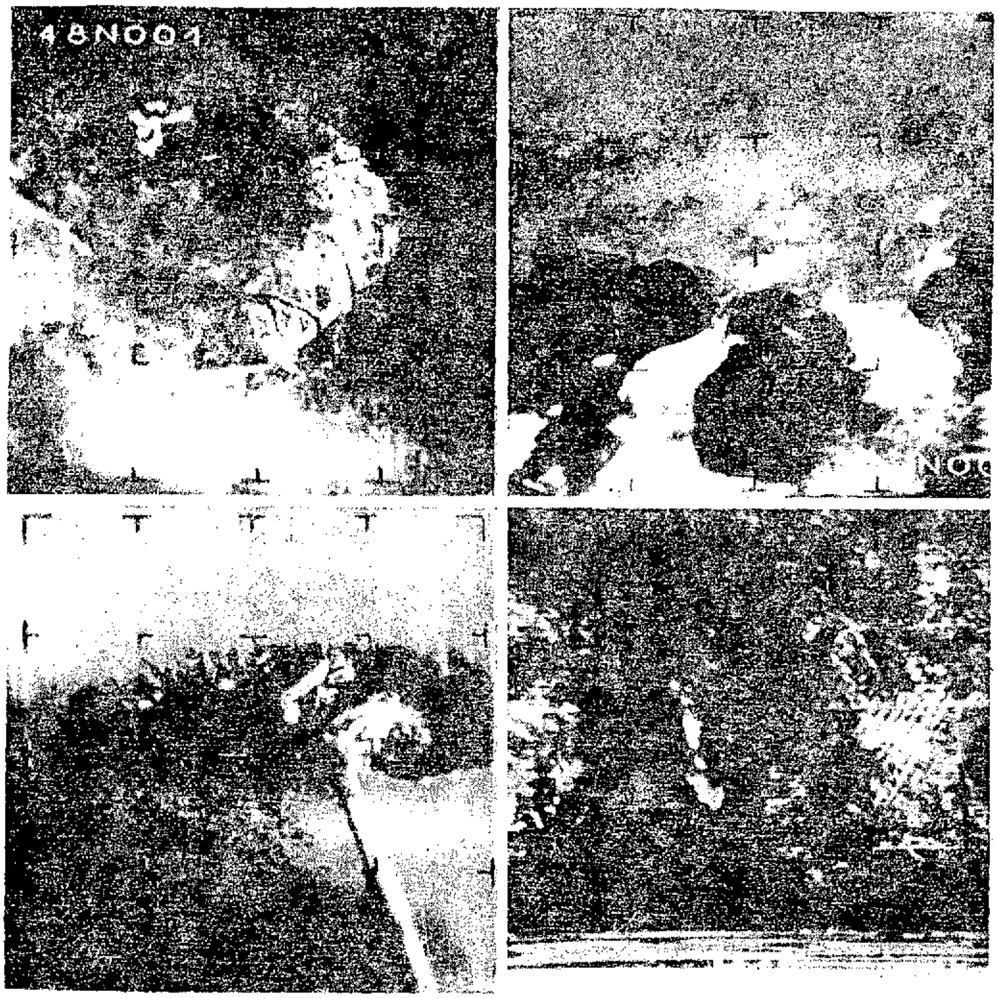

Four photographs of sections of the earth's surface from the Nimbus 1 and Tiros 2 American satellites
Top left -- Central France. Paris (indistinguishable)
Left bottom -- northern coast of Morocco,
Top right -- clouds over the Davis Bay,
Bottom right -- part of the Canadian province of Ontario. Only in this photograph were traces of earth civilization visible -- a rectilinear network of clearings in a forest standing out owing to newly fallen snow.

Nuclear explosions, which unfortunately sometimes occur on earth, can be observed from Mars as brief, bright flares. But since nuclear weapon testing occurs infrequently, and the flares from them are visible only for a brief moment, it is improbable that these blasts will be detected from Mars. If a special program of synoptic earth observations had been undertaken there, then perhaps the nuclear blasts actually will be detected. However, it is difficult to check whether a civilized Martian astronomer could be able to conclude from these brief flares that life exists -- let alone intelligence -- on earth. In fact even ourselves, inhabitants of the earth, could scarcely regard these barbaric experiments capable of leading to the extermination of life in our beautiful world as proof of intelligence!

Using an optical telescope, the Martian astronomer could detect seasonal changes over large areas of the earth's surface. Major seasonal changes in color and brightness occur in deciduous forests and in areas of extensive plantations, for example in the Ukraine and in the Midwest of the United States. However, all kinds of explanations can be sought up for these observations. Perhaps on earth there are areas with crystals, whose color depends on temperature or whose dark coloration depends on moisture content. Or, perhaps, these changes are due to some form of life on earth. But it is scarcely probable that the Martian astronomer would make a positive conclusion of the relationship between seasonal changes and life.

If the earth was observed regularly over several decades, then major changes could be detected on it -- for example, systematic destruction of forests. But could the Martian astronomer draw final conclusions from these observations? We observe these kinds of major and systematic "secular" changes on the Martian surface. These changes are interesting in themselves, but they of course cannot be regarded as indisputable proof that life exists. Many such changes have also been observed on the moon (though on the smallest scale), but the lunar surface is nearly certainly devoid of life.

Detailed spectroscopic investigations of the earth could have been carried out in Martian observatories -- for example, in searching for life spectra could have been investigated in ultraviolet light in which there is absorption by the organic matter on the planet's surface. But unfortunately, to detect absorption bands at wavelength of 3.5 microns and longer, they must be observed in reflected light. Light at a wavelength greater than 3.5 microns, on reaching the earth from Mars, is principally infrared earth radiation, and not sunlight reflected from it. It would be difficult for the Martian astronomer to find spectroscopic signs that organic matter exists on the earth's surface. /210

An attempt can be made to detect certain secondary atmospheric constituents of organic origin, for example, $CH_4$ and $N_2O$. Methane is a strongly reduced gas and it must be continuously formed in the earth atmosphere in order that oxidation not reduce its total content. Methane can be generated in the earth atmophere above all by methane bacteria transforming organic compounds into $CO_2$ and $CH_4$. Methane bacteria live in ooze at the bottom of ponds where there is much organic material and the conditions are anaerobic. Therefore it is often called swamp gas. Similar bacteria live in the stomachs of cows and other ruminants. Thus, one of the main sources of methane in the earth atmosphere are the intestinal gases of ruminants. So if a Martian observer detects methane in the earth atmosphere, then this will be a very important observation only if he will know how to interpret it. Incidentally, it is improbable that he will find the correct explanation.

What can we say about methane in the atmosphere of a Jupiter type planet? Soviet astronomer G. A. Tikhov suggested that methane on Jupiter originates from the same source as on earth, therefore there must be at least bacteria if not cows on Jupiter. Since we see that methane is part of primoidial planetary atmospheres, Tikhov's hypothesis can scarcely be taken seriously. However, we must emphasize how difficult it is to associate the presence of any molecule with biological activity.

Nearly all free oxygen in the earth's atmosphere is a product of photosynthesis in plants. The main source of oxygen is not the higher plants, but rather marine plankton filling the oceans. /211
The earth's crust is underoxidized and therefore is capable of entering further chemical reaction with atmospheric oxygen. If oxygen would not be produced continuously through biological activity, then it would have disappeared from the atmosphere in the relatively short time. If the amount of free oxygen in a planet's atmosphere is so small that it is detected the very limits of instrumental sensitivity, its presence can be accounted for by abiogenic hypotheses. But a higher level of oxygen as we have in the earth's atmophere can be accounted only by vigorous biological activity. However, here also two remarks must be made. An oxygen-rich atmosphere is capable of being produced through photodissociation of water. Moreover, it is doubtful that an intelligent anaerobic organism for whom oxygen is poisonous with which to consider an oxygen-rich atmosphere as a product only of biological activity.

If Martian astronomers have instruments enabling them to investigate the visible earth spectrum at a single wavelength of light, they would be able to observe the detectable increase in the amount of gases such as neon, argon, mercury, and sodium in the spectrum of the earth's night sky. Whether they would attribute this phenomenon to instrumental error, improvements in illumination engineering on earth, or to an advancing catastrophe -- we can only guess.

Ordinary spectroscopic measurements of the earth disclose on it the presence of enormous -- especially when compared to Martian conditions -- amounts of oxygen and water. Our temperatures would appear to be extremely high to Martians, and they would not detect ultraviolet radiation from our surface. It is quite probable that Martian scientists, based on an analogy with Mars, would conclude that there is no convincing evidence that there is life on earth and that further efforts to find life on it should be abandoned in the face of conditions so unfavorable.

However, there is one more method to detect life on earth. /212
Let us assume that Martian observatories were equipped with modern radiotelescopes -- instruments capable of measuring and recording radio emission from various celestial objects. A Martian astronomer, just like his earth colleague, would investigate radio emission of planets. He would find that Venus is a source of radio emission, possibly because its surface is hot, and he would also find that Jupiter is also a source of radio emission, since electrons in its magnetic field emit synchronous radiation, and so on. But he aimed his radiotelescope toward the earth, then he would make an amazing discovery: on the meter wavelength of a planet that in other respects is not at all outstanding, nearly as much radio intensity would be emitted as comes from the sun during a period of low activity! A planet that is bright as a star! In the meter wavelength the earth emits a million times more strongly than Venus or Mercury. This discovery could be made on Mars using even a modest radiotelescope.

Further investigations would show that various regions of the earth's surface emit dissimilarly; a periodic relationship would be found between radio emission and the earth's rotation about its axis. For example, when Africa or South and Central Asia face Mars, radio emission drops off sharply; but when Europe and North America face Mars, the emitted intensity rises abruptly. If these observations are conducted for a long time, the Martian astronomer could make another and even more amazing discovery: today the earth's radio emission is $10^6$ times more powerful than several decades ago. Martian astronomers would probably try to find a "natural" explanation for this phenomenon: such attempts would generally remain fruitless. The intelligent Martian astronomers would be forced to conclude that radio emission cannot be accounted for by the action of natural forces and that it can be the result only of artificial causes. They would conclude that there is intelligent life on earth: a discovery that is truly astounding!

The earth has several thousands of television transmitters. /213
If we take the mean intensity of each of these (about 20 kw), the frequency bandwidth at which they operate, the mean operating

time of each transmitter (let us say, 6 hours a day), and the fact that wavelength of any length in television broadcasting (from 1.5 to 6.0 m) pass through the atmospheres of the earth and Mars unimpeded, then we can calculate the intensity transmitted from the earth to Mars.

Radio astronomers can be interested in the fact that the so-called brightness temperature of the earth at television wavelength reaches a value of several hundreds of millions of degrees. This is 100 times stronger than the radio brightness of the sun in analogous wavelength during the period of low sunspot activity. In addition to television transmitters, there are numerous radio stations and other facilities giving off intense radiation in the ultrahigh frequency band.

We have extended this fantastic version of a Martian observatory studying the earth because we can thus see actual difficulties and the potentialities of success in remote investigations of planetary biology. If the hypothetical Martians could detect signs of life on earth only in the radio frequency band, then we must not be surprised by the fact that thus far we have no clear, indisputable, definite proof that there is life on Mars. Efforts to find rational radio broadcasts from Mars have thus far yielded only negligible results. The radio emission of Mars is only a incoherent noise of thermal radiation.

In the example of radio broadcasts from earth, we for the first time encounter the cosmis aspect of the biological activity of intelligent creatures. Advances made in technical civilization on our planet have greatly altered the character and intensity of its radio emission. The earth has begun to differ sharply from all other planets in the solar system. By means of painstaking investigation, an alien-planetary astronomer can probably be convinced that the signals have rational significance (in spite of the quality of many of the television programs). Thus, one of the key features of rational life is the fact that sooner or later its activity takes on cosmic overtones. /214

If we do not pick up distinct, intelligent radio emission from Mars, does this in itself mean that there are no highly developed forms of life there? Generally speaking, it does not. Much of the emission associated with television broadcasts is dissipated into space. Perhaps, radio emission from Mars would prove to be not intense enough to reach us. It is natural to assume that the more advance the technical civilization, the more economical are its methods of transmitting energy. It is possible that radio waves are focused into thin, discrete beams and the dissipation of energy from a source is reduced to a minimum. Thus, if a Martian civilization developed somewhat better than our own, then it could develop economical methods of electromagnetic communications that do not permit eavesdropping from the earth. But if the Martian civilization had developed much higher than our own, then it is amazing that we had not found scientific existence. Incidentally, if they have picked up our television broadcasts, then this may perhaps account for the absence of theirs!

American radio astronomer Frank Drake from Cornell University has pointed out that far no serious investigations have been made of radio emission from Mars in narrow frequency bands. Mars has been observed by wideband receivers in order to determine the temperature under its surface, but efforts to find intelligent signals have been conducted in the best of cases unofficially and nonsystematically. On the other hand, Drake states that there is little hope of success in such a program. If the Martians were ahead of us by only 50 years, we should have (with all the qualifications given above) found some other signs of their existence. But if they were behind us by the same 50 years, then they would have no radio broadcasts. These estimates are based on earth analogies and assume that a nearly continuous development of our technical civilization in recent years is typical of all other civilizations. Of course, we do not know for a certainty that this is so; on the other hand, this assumption is the most probable: in fact we do not have any contrary examples!

Since earth and Mars have existed approximately $5 \cdot 10^9$ years, then the probability of a successful search for an intelligent radio broadcast from Mars is $50:(5 \cdot 10^9) = 10^{-8}$, i.e., a millionth of a percent. Thus, without setting aside time for detailed investigations of Mars, directors of radio observatories perhaps are proceeding correctly. But since this search is fascinating, it is not amazing that observers steal a few minutes secretly between programmed observations in order to probingly, with the mixture of timidity and hope, gaze at far-off Mars.

# INHABITANTS OF NEAR SPACE /206

V. G. Fesenkov, Academician

People have ascended by rocket into space and have they encountered other people -- this present-day reality has now replaced long-standing utopian ideas of meeting intelligent creatures beyond the earth.

But if we think about it, these dreams played a certain role in attracting man's interest in space. Once, when the heliocentric system of Copernicus had gained universe acceptance and it has become obvious that our earth is only an ordinary planet in the solar system and that the sun itself is an ordinary star in our enormous galaxy, the existence of inhabited worlds also was accepted as quite indisputable. Man's striving to find some life in space and to enter into communication with representatives of other worlds became a strong impetus to advances in astronautics at the dawn of its birth. Purely scientific problems were then secondary, to some extent.

Does this mean that today, when man's penetration into space is related to planned and consistent scientific work that the ancient dream of contacts with intelligent creatures outside the earth has been forgotten?

By no means. Moreover, this has become a realm of science. /207
The problem of interplanetary civilizations has been quite seriously discussed at special conferences. Such conference was held in our country in 1964, and two years later -- in the United States. Projects for detecting other civilizations and for possible contacts with them were drawn up. And overall careful observations thus far have not yielded results, anytime astronomers discover some new unusual object in the universe, first of all the suggestion of its artificial origin is raised. Thus it was, for example, recently with pulsars emitting radiation with amazingly regular oscillations, which some scientists took as signals sent by other civilizations.

The yearning to meet intelligent creatures beyond the earth to prove to ourselves that space is inhabited is as vibrant as ever in man.

Moreover, evolution of astronautics itself has been such that we are finding more and more reason to speak about the inhabitability of near space. True, its "inhabitants" are not emigrants from other planets, but emissaries of our earth.

# LIFE IN THE UNIVERSE -- AND THE MOON /210

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The investigation of lunar samples is important not only to solve the question of the origin of our planet's natural satellite. It is of paramount importance also in solving the fundamental problem of modern planetology -- clarifying the question of the origin of the solar system. It is obvious that by studying lunar rock samples in a laboratory, one can gather much information that could not be obtained with astronomical methods of observation. This includes, first of all, determining the age of samples studied, estimating their temperature of formation, and their elemental and mineralogical composition. These experiments are at the present time difficult to carry out on the lunar surface due to technical limitations.

Also of high interest is the problem of searching for and studying organic compounds in lunar rocks intimately associated with the problem of the origin of life in the solar system.

Results of astronomical observations and the examination of the chemical composition of meteorites indicate that the abiogenic synthesis -- that is, unrelated to the life activity of any organ- /211
isms -- of a great many organic compounds of varying complexity is going on in various regions of our galaxy. Molecules of water, methane, and ammonia have been detected in interstellar space. These simple compounds contain atoms of oxygen, carbon, hydrogen, and nitrogen. As a result of abiogenic synthesis, certain biologically vital compounds can be formed from them. And actually, in recent years radio astronomy methods have been employed in detecting molecules of hydrogen cyanide and formaldehyde at great distances from the earth; under suitable conditions, quite complex organic molecules can be constructed from these, for example, bases of nucleic acid and amino acids.

No less interesting data have been obtained from studying various meteorites -- in particular, the so-called carbonaceous chondrites. Hydrocarbons, sugars, fatty acids, and amino acids have been isolated from them. We can with some certainty state that at least some of these compounds are of extra-terrestrial origin and were formed abiogenically, which could have been promoted by energy sources such as, for example, cosmic rays, ultraviolet radiation, and elevated temperatures. To appreciate the problem of the origin of life in the solar system, exceptional interest inheres in the question of the possible abiogenic synthesis of organic compounds on planets and the moon. /212

The moon has practically no atmosphere. Therefore, synthesis can occur here through the interaction of solar wind with inorganic compounds in the surface layer. It is also possible that the formation of organic compounds is associated with the fall of meteorites on the moon. And nonetheless, it is difficult to find detectable constant concentrations of any organic compounds in the surface layer of this celestial body; for most organic compounds the temperature gradient on the moon, ultraviolet and cosmic rays reaching its surface can act destructively. Moreover, their synthesis is markedly impeded by the absence of water. So we can assume that only traces of the simplest hydrocarbons, for example, methane, will be found in the surface layer of the moon. Actually, analysis of samples brought by American astronauts showed an extremely low carbon content. The electric drill of the Luna 16 station collected rock samples to a depth of 350 mm. And it is possible that the examination of samples taken from this depth can yield qualitatively different results. /213

A hypothesis is held to the effect that the abiogenic synthesis of organic molecules may have occurred at one of the early stages of lunar formation. If it is correct, then these compounds may be preserved in the deep layers unchanged for billions of years. And in fact it is obvious that here the conditions may differ radically from surface conditions. Moreover, differences in chemical composition of samples taken from various sections of the lunar surface are also possible.

Since the temperature at which lunar rock samples were formed is estimated at about 1000° C, much interest lies in the examination of possible gaseous inclusions. Information about these would assist in proper evaluation of the ways in which the moon was formed and in determining the level of evolution of organic matter.

Study of the properties of lunar rock, including their examination for content of organic compounds, will yield scientific information whose importance is hard to overestimate.

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